Universidade de Aveiro Departamento de Química

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Research and market trends in the area of macro- and microalgae: patent analysis and bibliometrics

Tendências de investigação e de mercado na área das macro- e microalgas: análise de patentes e bibliometria

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Tese apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Biotecnologia, Ramo de Biotecnologia Alimentar, realizada sob a orientação da Professora Doutora Ana Daniel, Professora Auxiliar do Departamento de Economia, Gestão, Engenharia Industrial e Turismo da Universidade de Aveiro, e da Professora Doutora Maria do Rosário Gonçalves dos Reis Marques Domingues, Professora Associada com Agregação do Departamento de Química da Universidade de Aveiro.

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o júri

presidente

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palavras-chave

Macroalga, microalga, aplicação alimentar, vigilância tecnológica, previsão tecnológica, análise de patentes, análise bibliométrica

resumo

As algas (macroalgas e microalgas) são organismos aquáticos e fotossintéticos que contêm uma enorme variedade de compostos naturais com um elevado valor acrescentado para diferentes setores, com destaque para aplicações alimentares/ nutrição humana. De facto, 83 % das macroalgas colhidas e cultivadas são consumidas pelos seres humanos como fonte direta de alimento ou como aditivo alimentar (principalmente ficocolóides), e a biomassa de microalgas tem sido usada principalmente nos mercados de saúde alimentar nas últimas décadas. As provas científicas estão constantemente a surgir e apoiam o vasto potencial das algas na saúde e nutrição humana. Este trabalho teve como objetivo usar a Vigilância Tecnológica para detetar oportunidades de inovação tecnológica e novas ideias nos setores das macro e microalgas e, consequentemente, usar abordagens de Previsão Tecnológica para estudar o impacto das tecnologias de algas em algum momento no futuro (tendências tecnológicas). Utilizando bibliometria de patentes e bibliometria de literatura, foram estudadas e analisadas, respetivamente, as tendências de mercado e de investigação. O portfólio de patentes das macroalgas é muito maior (49582 patentes) do que o portfólio de patentes das microalgas (12524 patentes), o que também foi observado para a análise bibliométrica, onde as macroalgas possuíam 731 documentos publicados na área alimentar enquanto as microalgas possuíam 376 documentos. As aplicações sobre macroalgas estão mais relacionadas com a Química Alimentar e Química Fina Orgânica (KAO, produtora de produtos químicos & cosméticos, é o principal *player*), e as aplicações sobre microalgas estão mais relacionadas com a Biotecnologia (*ENN Science & Technology Development*, atua no campo da energia, é o principal *player)*. Também foi observado que no estudo bibliométrico, as microalgas têm mais áreas temáticas, com mais documentos publicados, relacionadas com Biotecnologia, Ciências Ambientais e Combustíveis & Energia do que relacionados com Ciências Alimentares, como ocorre para o caso das macroalgas. A China é o país que detém o maior portfólio de patentes das algas, porém, relativamente à literatura publicada sobre o tema, a Europa é o maior investidor em estudos de algas relacionados com aplicações alimentares, em particular a Espanha. A análise de coautoria entre os autores mostra que os autores Portugueses lideram a investigação nas macroalgas, com o maior número de itens relacionados, e os autores Belgas lideram nas microalgas. Em termos de coautoria entre instituições, a falta de cooperação/relacionamento entre instituições/organizações no caso de estudo das microalgas não foi observada no caso das macroalgas. Tanto para as macro- como microalgas a coautoria entre países deu-nos a informação da cooperação entre diferentes países, com destaque para a Espanha. As palavras chave “alimentos funcionais”, “atividade antioxidante” e “antioxidante” são termos importantes para a análise bibliométrica de algas, apesar destes termos serem ausentes na análise de patentes. Assim, as algas não são apenas uma tendência de mercado (com diferentes aplicações tecnológicas), mas também o são na literatura académica, relacionada com Ciência e Tecnologia Alimentar, em linha com as recomendações da Economia Azul para um futuro mais sustentável.

keywords

Macroalgae, microalgae, food application, technology surveillance, technology forecasting, patent analysis, bibliometric analysis

abstract

Algae (macroalgae and microalgae) are aquatic and photosynthetic organisms that contain a huge variety of natural compounds with a high added value for different sectors, with highlight for food applications/human nutrition. In fact, 83 % of the seaweed harvested and cultivated is consumed by humans as direct food source or as food additive (mostly phycocolloids), and microalgae biomass has been mainly practiced in the markets of food health during the last decades. Scientific proves are constantly appearing and supporting the vast potential of algae in human health and nutrition. This work aimed to use Technology Surveillance to detect technology innovation opportunities and new ideas in macro- and microalgae sectors and, consequently, use Technology Forecasting approaches to study the impact of algae technologies at some time in the future (technology trends). Using patent bibliometrics and literature bibliometrics, were studied and analysed, respectively, market and academic research trends. The seaweed patents portfolio is much bigger (49582 patent) than microalgae patents portfolio (12524 patents) which is also observed for the bibliometric analysis, where macroalgae has 731 published documents in the Food area whereas microalgae has 376 documents. Seaweed applications are more related with Food Chemistry and Organic Fine Chemistry (KAO, producer of chemistry & cosmetic products, is the major key player) and microalgae applications are more related with Biotechnology (ENN Science & Technology Development, operates in the energy field, is the major player). Was also observed in the bibliometric study that microalgae have more subject areas, with more published documents, related with Biotechnology, Environmental Sciences and Energy Fuels than related with Food Science, which occurs for macroalgae case. China is the country that detain the major algae patents portfolios, however in relation to the published literature on the subject, Europe is the largest investor in algal studies related with food applications, in particular Spain. The co-authorship analysis between authors show as that Portuguese authors lead in macroalgae research, with most connected items, and Belgian authors lead in microalgae research. In terms of co-authorship between institutions, the lack of cooperation/relationship between various institutions/organizations in the microalgae case study was not observed in the case of macroalgae. Both for macro and microalgae the co-authorship between countries gave us the information of the cooperation between different countries, with highlight for Spain. The keywords “functional food”, “antioxidant activity” and “antioxidant” are important terms for macro and microalgae bibliometric analysis despite the absence of those terms in the patent analysis. Thus, algae are not only a trend for market (with different technology applications) but also in academic literature, related with Food Science and Technology, considering the recommendations of Blue Economy for a more sustainable future.

INDEX

LIST OF ABBREVIATIONS

- BMI – Body Mass Index
- CAGR – Compound Annual Growth Rate
- CI – Competitive Intelligence
- CII – Current Impact Index
- CSIC – *Consejo Superior de Investigaciones Científicas*
- DBP – Diastolic Blood Pressure
- DHA – Docosahexaenoic Acid
- EPA – Eicosapentaenoic Acid
- EPO – European Patent Office
- FCP – Fucose-containing Polysaccharide
- GM – Global Mood
- IP – Intellectual property
- IPC – International Patent Classification
- IPL – Institute Polytechnic of Leiria
- IPMA – *Instituto Português do Mar e da Atmosfera*
- JPO – Japan Patent Office
- NAX – Natural Astaxanthin
- OECD – Organisation for Economic Co-operation and Development
- PBRs – Photobioreactors
- PCT – Patent Cooperation Treaty
- POMS – Profile of Mood States
- PUFAs – Polyunsaturated Fatty Acids
- R&D – Research & Development
- ROS – Reactive Oxygen Species
- SBP – Systolic Blood Pressure
- S&T – Science & Technology
- SIgA – Secretory Immunoglobulin A
- TCT – Technology Cycle Time
- TF – Technology Forecasting
- TS – Technology Surveillance
- UM – University of Minho
- UP – University of Oporto
- USPTO – United States Patent and Trademark Office's
- WIPO – World Intellectual Property
- WoS – Web of Science

LIST OF FIGURES

LIST OF TABLES

CONTEXTUALIZATION

The main goal of this work was to assess the present and analyse the future market trends and future research trends in macro and microalgae areas, through technology surveillance and technology forecasting approaches. Three starting questions arise, to which this study seeks to find an answer:

a) How is the algae market segmented at present?
b) Which are the potential market applications of macro and microalgae?
c) Are algae market trends the same as the research/academic trends for human nutrition/food science?

This thesis is divided in four distinct sections. **Section 1** comprises the state of the art concerning (*i*) characterization, major applications, and market evaluation of macro- and microalgae; (*ii*) the potential of algae for human's health and nutrition, and the promise of algae blends; (*iii*) importance of technology surveillance and technology forecasting approaches; and (*iv*) patent analysis. In **section 2** a brief contextualization about Intellectual Property is presented and a detailed description of the methodologies used for patent analysis and bibliometric analysis is provided. **Section 3** presents and discusses the results from the patent analysis (patent data mining and patenting trends in algae technological domains) and bibliometric analysis (a more descriptive analysis using Web of Science, and co-authorship and co-occurrence analysis using VOSviewer) for macro- and microalgae, separately. For last, **section 4** provides the main conclusion of this thesis.

1. State of the Art

1.1 General Considerations about Algae

Aquatic and photosynthetic organisms are usually referred as algae. Those organisms are distributed through diverse groups that contain several known species with different size, morphology, physiology, life cycle and, inclusively, different occurrence. Microalgae and macroalgae are the two most used categories to group algae: microalgae are microscopic photosynthetic organisms, being mostly of them unicellular and, in turn, macroalgae are macroscopic organisms composed of multiple cells (John et al. 2011) . An algae can have a few micrometres or tens of meters size (Sudhakar et al. 2018). More than 30.000 species of algae have been already described – being their scientific study called phycology (Gomez-Zavaglia et al. 2019).

1.2 Macroalgae

1.2.1 Characterization and major applications

Seaweed is the generic term for macroalgae which are macroscopic and multicellular marine algae that form a vital part of coastal ecosystems of the world (Sangha et al. 2014). These eukaryotic aquatic plants (encompassing approximately 9000 species) are significantly different from terrestrial plants, since seaweeds contain high contents of water (90 % fresh wt); carbohydrates (25-50 % dry wt); protein (7-15 % dry wt) and low lipid content (1-5 % dry wt) (Sudhakar et al. 2018). Seaweeds also contain phytohormones, pigments and a wide variety of relevant secondary metabolites (Bedoux et al. 2014). Macroalgae can be classified/divided into three major divisions /phylum according to their associated pigmentation: Ochrophyta or brown algae, Rodophyta or red algae, and Chlorophyta or green algae (Bedoux et al. 2014, Krastina, Romagnoli, and Balina 2017) (Fig. 1).

Macroalgae biomass for downstream processing is obtained from three principle sources: direct harvesting – mechanical or manual (Ghadiryanfar et al. 2016) – of the seaweed from the marine environment; collection of dead seaweed from shore; and through culturing selected seaweed species (Sudhakar et al. 2018). Only 6 % of global seaweed comes from natural stocks, the rest is obtained by cultivation. Macroalgae farm cultivation methods include far-shore farms (Offshore farms); in-shore coastal farms (Onshore farms, including nearshore farms), and ponds built on land. Offshore farms are the farms that are constructed in deep water or closer to the water surface, in turn, nearshore farms are those that are located near shorelines (Ghadiryanfar et al. 2016). The major environmental factors that impact in the growth of the seaweed are: location; water quality; salinity; depth; temperature; current; land quality fauna and climatic factor (Sudhakar et al. 2018).

Figure 1. Examples of brown, red and green seaweed: a) Saccharina latissimi; b) Palmaria palmate; c) Ulva rigida (Source: inaturalist)

Nowadays, seaweed represent a promising source of natural products with high added value for different areas and sectors, such as:

- **Agriculture** – since seaweeds are a good source of organic matter and fertilizer nutrients, for example (Khan et al. 2008);
- **Biofuels** – algae has the ability to assimilate considerable amounts of biomass that can be converted into fermentable sugars, being those converted to bioethanol production, for example (John et al., 2011; Ghadiryanfar et al., 2016);
- **Bioremediation** – algae can act as decontaminating agents, for the removal or biotransformation of pollutants from wastewater (Bwapwa, Jaiyeola, and Chetty 2017);
- **Cosmetic applications** – seaweeds extracts demonstrate a wide range of different activities in relation to different cosmetic parameters, such as antiaging, photoprotection or anti-inflammatory effects (Bedoux et al. 2014);
- **Food applications/ feed for livestock** – some seaweeds (edible seweeds) can be used as whole foods since it contain high content of fibres, high concentrations of proteins and although the low quantity of total lipids, seaweeds comprise ω-3 and ω-6 polyunsaturated fatty acids (PUFAs). Macroalgae can also be utilised

in hydrocolloid industry, for food applications, due to their rich chemical composition in polysaccharides. Recent research about seaweed use on animal feed supplement (protein, polysaccharides or enriched with PUFAs), also provide promising results, with a lot of potential (Cikoš et al. 2019; Løvstad Holdt and Kraan 2011). The topic of food applications will be discussed later with more detail in the section 1.4.1;

- **Pharmacology/medical applications** – seaweeds contain substances that confer antiviral, antibiotic, anti-inflammatory, anti-cancer and antibacterial activity, having also other multiple substances with biological activities (Afzal Rizvi & Shameel, 2005; Smit, 2004);

1.2.2 Market Applications

Despite the large number of applications of macroalgae, approximately 83 % of the seaweed harvested and cultivated is consumed by humans as a direct food source or as food additive (White and Wilson 2015). Currently, 221 species of algae are collected globally: 145 are for human nutrition, and 101 for phycocolloid production, being the phycocolloids classified into three major groups: alginates, carrageenans and agars. These include 125 rhodophytes, 64 ochrophytes and 32 chlorophytes (Gomez-Zavaglia et al. 2019).

The major producing countries of seaweeds are located in the east and southeast Asia. In fact, the most dominant producers are China (62.8 %), Indonesia (13.7 %), Philippines (10.6 %), Republic of Korea (5.9 %), Japan (2.9 %) and Democratic People's Republic of Korea (2.8 %) (Ghadiryanfar et al. 2016). 94 % of worldwide seaweed are produced by aquaculture, which also means that from almost 21 million tons of seaweeds utilized, only 800.000 of this is harvested from the wild (White and Wilson 2015). Since 1970, the production of seaweed has been steadily increasing with a year-on-year growth rate of, approximately, 8 %. Indeed, 21 million tons of aquatic plants were produced globally in 2011, being 99 % of the production comprised of seaweed only (Rajauria 2015).

In North America and Europe, macroalgae are an underexploited resource, despite the increasing interest in the seaweed market due to seaweeds potential applications in so many areas, as already mentioned (Bak, Mols-Mortensen, and Gregersen 2018). European macroalgae industry uses seaweeds mainly from wild harvesting, for the production of phycocolloids (Van Den Burg et al. 2016). This has led to a low production of seaweed in Europe. In fact, in 2015, Europe only produced a few hundred tonnes of dry weight of macroalgae, while Asia produced 2.7 million tonnes (Bak, Mols-Mortensen, and Gregersen 2018). However, due to the potential of macroalgae industry in Europe, it has been recognized that more widespread seaweed aquaculture is needed in the near future. Thus it is expected that seaweed aquaculture will become more extensive in Europe over the next decades (Marine Institute 2005). Currently, Norway, France and Ireland are the dominant seaweed suppliers, whereas Spain, Portugal and the United Kingdom are small producers and suppliers (Vieira et al. 2018).

A forecast accomplished by Allied Market Research evaluate a global seaweed market size of $ 4,097.93 million in 2017 and predicted to reach $ 9.075.65 million by 2024, registering a Compound Annual Growth Rate (CAGR) of 12.0 % from 2018 to 2024 (Allied Market Research 2018).

1.3 Microalgae

1.3.1 Characterization and major applications

Microalgae are microscopic, unicellular, or multicellular, and photosynthetic microorganisms that are considered one of the most ancient living forms on planet earth. They are auxotrophic, and produce biomass and oxygen (O_2) by using carbon dioxide (CO_2) and inorganic nutrients in presence of sunlight (Mishra et al. 2019). Microalgae are a phylogenetically diverse group, including several different phyla and classes of organisms, being cyanobacteria included in some cases (Camacho, Macedo, and Malcata 2019). Thus, microalgae mainly comprises four major groups: diatoms (*Bacillariophyceae*), green algae (*Chlorophyceae*), golden algae (*Chrysophyceae*) and cyanobacteria (blue-green algae) (*Cyanophyceae*) (Carlsson et al. 2007).

Microalgal biotechnology began to develop and prosper from the mid-20th century, and, despite the large number of microalgal species (more than 50.000) discovered, only 30.000 species have been studied so far (Nethravathy et al. 2019). The huge abundance of those organisms on earth is related with their ability to inhabit diverse ecological habitats, ranging from freshwater, brackish water, seawater or moist soils and rocks, since those are equipped to prosper in extreme temperatures and pH conditions (John et al. 2011; Camacho, Macedo, and Malcata 2019). The ratio of biochemical components or the ratio of proteins/carbohydrates/lipid of algae is species specific (Sudhakar et al. 2018), however the protein content in microalgae can range from 30 % to 55 % (dry wt); the lipid content varies between 20 % and 50 % (dry wt) and, approximately, 10 % of dry matter are carbohydrates. Pigments, as carotenoids or chlorophylls, vitamins and phenolic compounds are also present (Villarruel-López, Ascencio, and Nuño 2017).

Microalgae biomass processing involve three major steps: cultivation; harvesting and extraction (not always a necessary step, depends on the desired products since microalgae biomass can be used as food supplement). In the **cultivation** step, specie selection and definition of the sustainability and economic viability of the cultivation system are the main key tasks. Microalgae can growth in batch or continuous system (Rizwan et al. 2018). Algae mass production methods include open ponds, closed photobioreactors (PBRs) and immobilized culture systems. Open ponds are the oldest and simplest systems for algal culture, where microalgae are cultivated under conditions identical to those in the external environment. It becomes relevant to refer that there are many different designs for open-pond systems as raceway ponds, circular ponds, or unstirred ponds. Closed PBR are being popular in the cultivation of microalgae, and these systems are not directly exposed to the atmosphere; in reality, they are covered with a transparent material or contained within transparent tubing. Also, photobioreactors have different designs but most of them consist of tubes of various shapes, sizes, and lengths. In Immobilized Culture Systems unialgal cultures are immobilized in a polymeric matrix or attached algal communities grow in shallow, artificial streams or on surfaces of rotating biological contactors. Non-suspend system algae cultivation includes enclosure and non-enclosure methods (Shen, Yuan, Pei, Wu 2009). After the cultivation step, **harvesting** takes place, and during this step the microalgal biomass is separated from the culture medium. Finally, when applicable, in the **extraction** step there are highly specific processes that strongly depends on the desired products. Thus, this step is crucial and entails constraints to produce fuels, some food and feed products as well as for high-value products like β-carotene or polysaccharides. Solvent extraction is an example that is commonly employed (Rizwan et al. 2018). As macroalgae, also microalgae are a potential renewable source which can be used for different commercial applications such as:

- **Agriculture** – Microalgae, particularly cyanobacteria, can be considered one of the main biological agents for the control of pathogenic fungi and soil-borne diseases in plants, due to their production of biologically active compounds (Vieira Costa et al. 2019).
- **Biofuels** – Microalgae as *Chlorella* spp. or *Dunaliella* spp. are known to contain a large amount of starch and glycogen, useful as raw materials for ethanol production. Due to their ability to assimilate cellulose, microalgae can also ferment bioethanol (John et al. 2011);
- **Cosmetics** – Microalgal compounds are normally used in cosmetics products as an antioxidant, thickening, and water-binding agents. Extracts from microalgae are mostly used in face and skin care products, being also used in the production of hair care and sun protection products (Rizwan et al. 2018);
- **Environmental applications** – Microalgae can be used for Bio-mitigation of CO_2 emission, once microalgae are usually capable of assimilating CO_2 from the atmosphere, power plants, and soluble carbonates. Microalgae can also successfully remove heavy metals and pollutants from the wastewater (Rizwan et al. 2018);
- **Human and Animal nutrition** – Due to microalgae diverse chemical properties, they can be used as nutritional supplement (usually commercialized in tablet, capsule, or powdered form) or represent a source of natural food colorants for human nutrition, for example. Nowadays, food products containing microalgae in their formulations is also a trend. Those products can include the whole microalgal biomass in their formulation or include a microalgae derived compound. Microalgae can also be incorporated into the feed for a wide variety of animals, as fish (aquaculture) or farm animals (Spolaore et al. 2006; Lafarga

2019). An extended discussion about the use of microalgae in human nutrition is presented in the section 1.4.2;

- **Pharmaceuticals** – Microalgae-derived bioactive compounds can provide natural, safe, and sustainable compounds when compared to the conventional pharma products. For example, astaxanthin, a carotenoid present in microalgae, can act as an antioxidant and also as an anti-inflammatory component, enhancing the antibody production (Nethravathy et al. 2019).

1.3.2 Market applications

Due to its wide range applicability, numerous companies/industries are continuously exploring the use of microalgae to produce many commercial products (Katiyar and Arora 2020). There are around 110 commercial producers of microalgae present in the Asia-Pacific region, with producing capacity ranging from 3 to 500 tons/ year. In fact, about nine-tenths of all algal cultivation is located in Asia. Despite the large number of microalgal species, only very few of them have commercial importance, such as *Spirulina*, *Chlorella*, *Haematococcus*, *Dunaliella*, *Botryococcus*, *Phaeodactylum*, *Porphyridium*, *Chaetoceros*, *Crypthecodinium*, *Isochrysis*, *Nannochloris*, *Nitzschia*, *Schizochytrium*, *Tetraselmis* and *Skeletonema* (Sathasivam et al. 2019).

Among the algal-derived products, the production of dried *Spirulina spp*. is the most relevant with around 12.000 tons per year, followed by *Chlorella spp*. and *Dunaliella salina*, with 5000 and 3000 tons per year, respectively (Koyande et al. 2019). Indeed, *Spirulina* biomass dominates the market and South-Asian countries, mainly China, India, and Taiwan, contribute to 70 % of total production. It is envisaged that their production is further going to increase with the increasing demand because markets are seeing the big shifts to plant-based nutrition (Nethravathy et al. 2019). Thus, the CAGR of algae-based products is expected to cross 5.2 %, and the market value will stand at US$ 44.6 billion by 2023 (Koyande et al. 2019). Food and beverage segment is expected to grow at a CAGR of 6.9 % (Nethravathy et al. 2019) , which is corroborated by the fact that the microalgae biomass was mainly used in the markets of food health during the last decades, in the form of powder, tablets, capsules or pastilles (Gujar et al. 2019). Also, carotenoid pigments as astaxanthin, β-carotene, fucoxanthin and lutein, have received more and more attention due to its potential use in nutraceuticals, pharmaceuticals, food and animal feed, cosmetics and more. Thus, the market value of carotenoids is expected to reach $1.53 billion by 2021 (Ambati et al. 2018).

Europe accounted for nearly one-third of the global microalgae-based products market in 2018, making it the most significant regional market due to the high volume of technology development activities along with Research & Development (R&D) for the use of microalgae for biofuel production. Moreover, Europe owns specific structural, economic and logistical resources that boosts its position in microalgae research and applications (Transparency Market Research 2019).

1.4 Algae in human's health and nutrition

1.4.1 The potential of macroalgae

Seaweeds have the potential to provide a rich and sustainable variety of macro and micronutrients to the human diet (Cherry et al. 2019). In fact, it has been particularly used in the Asian traditional cuisine, being also widely explored for its other qualities such as extraction of phycocolloids (Rajapakse and Kim 2011). Apart from its proven nutritional properties/nutritional value, that will be discussed later, bioactive compounds found in macroalgae have attracted the interest of health-conscious societies, once seaweed is considered a remarkable medicinal food (Rajapakse and Kim 2011). Thus, seaweed have shown to provide a rich source of natural bioactive compounds with antiviral, antifungal, antibacterial, antioxidant, anti-inflammatory and other beneficial biologic activities (Suganya et al. 2016).

There are a considerable number of studies related with the medicinal/health beneficial properties of seaweed, despite their nutritional value. For example, Hitoe et al. 2017 studied the effect of the carotenoid fucoxanthin [1] (1 or 3 mg daily) in double-blind placebo-controlled study. The capsules containing fucoxanthin or placebo capsules were administered for four weeks to male and female Japanese adults with a body mass index (BMI) between 25 kg/m^2 and 30 kg/m^2. Before and after treatment different

[1] Fucoxanthin is a xanthophyll (a type of carotenoid) present in brown algae that is responsible for their specific coloration (Afonso et al. 2019)

parameters, such as body weight and abdominal fat area, were evaluated. In the 3 mg day group, significant decreases occurred in BMI, visceral fat area and body weight compared to placebo and before ingestion. In the group with the treatment of 1 mg per day did not show changes of body fat parameters [2] as the group with 3 mg/day showed, but allowed a reduction in total fat area and subcutaneous fat area (Computerized tomography parameters) and more significant difference in circumference parameters than the 3 mg day group. The study conclude that treatment with fucoxanthin (3 mg/day) reduced body weight, BMI and abdominal fat, being the **fucoxanthin able to improve a moderate overweight state in both men and women** (Hitoe and Shimoda 2017). Hata et al. 2001 analysed the effects of *Undaria pinnatifida* (wakame) on blood pressure, and serum biochemical parameters in hypertensive subjects. An experiment was conducted with a group of patients receiving a daily dose of 5 g of dried wakame powder packed in 12 capsules, and a control group. The study was carried out for eight weeks and during four weeks the patients were examined clinically. The study concluded that the systolic blood pressure (SBP) in the group administered with the wakame dropped 13 mmHg below the baseline after four weeks and 8 mmHg after eight weeks. Also, the diastolic blood pressure (DBP) decreased by 9 mmHg after four weeks and by 8 mmHg after eight weeks. The difference in reduction in SBP and DBP were significant between the control and wakame groups. The study concludes that **wakame has beneficial effects as a dietary regimen in the treatment of hypertension** (Hata et al. 2001).

Regardless of the multiple studies performed with seaweed and their bioactive compounds in order to find new evidences about their medical uses, macroalgae are a great and sustainable nutritional food, as already referred. The seaweed species usually used for direct consumption are: *Ulva rigida*, *Monostroma sp*., *Enteromorpha sp*., *Laminaria sp*., *Undaria pinnatifida*, *Hizikia fusiforme*, *Himanthalia elongata*, *Eisenia bicyclis*, *Ascophyllum nodosum*, *Fucus vesiculosis*, *Porphyra sp*., *Cladophora glomerata*, *Microspora floccose* and *Palmaria palmata* (van der Spiegel, Noordam, and van der Fels-

[2] They are: Body weight; BMI; Body fat ratio; Fat mass; Lean mass; Muscle mass; Basal metabolic rate; Caloric intake; Fat intake.

Klerx 2013). In the table 1 the common names of the most popular edible seaweeds and their Latin names are presented.

Table 1. Latin and common European names of edible seaweeds (Adapted from (Macartain et al. 2007))

LATIN NAME	MOST COMMON NAME
Ascophyllum nodosum	Egg wrack
Laminaria digitata	Kombu/Konbu
Laminaria saccharina	Royal or Sweet Kombu
Himanthalia elongata	Sea spaghetti
Undaria pinnatifida	Wakame
Porphyra umbilicalis (or other spcies)	Nori
Palmaria palmata	Dulse or Dillisk
Chondrus crispus	Irish moss or Carrigeen
Ulva lactuca	Sea lettuce
Enteromorpha (Ulva) intenstinalis	Sea grass

Despite the variety of edible seaweeds recognized as novel foods, the nutritional composition of brown, red, and green seaweeds vary among species, seasons, and ecology of the harvesting location (Cherry et al. 2019). Usually, macroalgae are high in minerals due to their marine habitat, and the diversity of the minerals they absorb is wide: calcium, potassium, magnesium, sodium, cooper, iron, iodine, and others. Typical nutritional analysis of seaweeds have also identified high levels of carbohydrates. Though, there are two main types of polysaccharides in seaweeds, respectively with structural and storage roles. Structural polysaccharides are similar to terrestrial plants and are mostly celluloses, hemicelluloses and xylans. Storage polysaccharides, as alginates or carrageenans, are more specific of seaweed species and, once they are not digested to any great extent in the gut, they are referred as fibers – representing the most commercially exploited component in macroalgae (Macartain et al. 2007). Seaweeds have a very low lipid content, ranging from 1 % to 5 % of dry matter and much of this lipid content is made up of PUFAs, much of it occurring in the form of omega-3 and omega-6 lipids, being the eicosapentaenoic acid (EPA) and docosahexaenoic acid

(DHA) the two most important fatty acids of marine origin – belonging to ω-3 fatty acids. Note that the content and composition of lipids can be greatly varied depending from specie to specie (Rajapakse and Kim 2011). Additionally, seaweed protein is rich in glycine, arginine, alanine, and glutamic acid, and contains all the essential amino acids. However, macroalgae appears to have a limited amount of lysine and cystine when compared with other protein-rich food sources. Seaweed contains as well several vitamins, both water soluble, such as B and C, and lipid soluble, such as A and E at varying levels (Rajapakse and Kim 2011). A general chemical composition of some well-known brown, red and green seaweed is presented in the table 2.

Table 2. Chemical composition of selected edible seaweed (% dry weight) (Adapted from (Pereira 2016)*)*

SPECIES	ASH (%)	DIETARY FIBER (%)	CARBOHYDRATE (%)	LIPID (%)	PROTEIN (%)
Brown algae					
Undaria pinnatifida	26-39	16-46	45-51	1.5-4.5	12-23
Laminaria digitata	38	37	48	1	8-15
Red Algae					
Porphyra umbilicalis	12	29-35	43	0.3	29-39
Palmaria palmata	15-30	29	45-56	0.7-3	8-35
Green Algae					
Ulva lactuca	13	29-38	36-43	0.6-1.6	10-25
Ulva rigida	29	38-41	43-56	0.9-2.0	18-19

Thus, seaweeds are a great source of bioactive compounds, macro and micronutrients, and their potential as direct food is unquestionable. Seaweed can be consumed in many forms as raw, dried or cooked (Mahadevan 2015). Finally, it turns relevant to clarify that phycocolloids, used as food additives (Fleurence 2016), are the major industrial product derived from algae at the present time (Suganya et al. 2016), but seaweeds are an incredible sustainable source of many other components with potential application in food, feed , nutraceutical, cosmetic and pharma industries.

1.4.2 The potential of microalgae

Despite many species of green algae have been utilized as food since ancient times, the cultivation of microalgae started only a few decades ago once it became clear that the fast-growing world population was likely to suffer a lack of sustainable and nutrition-rich food stuffs (Khan, Shin, and Kim 2018). Microalgae are considered one of the most promising feedstock materials for developing an ecological supply of commodities, including food products. As seaweed, also microalgae have a great potential to improve human's wellbeing, since they produce natural compounds with important biological activities, as already mentioned in the case of macroalgae (Matos et al. 2016).

For instance, Otsuki et al. 2011 analysed the effects of *Chlorella*-sp. derived supplement on mucosal immune functions. The purpose of this study was to investigate whether ingestion of *Chlorella*-sp. increases the salivary secretory immunoglobulin A (SIgA) secretion in humans using a study design – note that SIgA is the first line of defence for the human body against pathogenic microbial invasion. Hereupon, fifteen men took 30 placebo, and 30 *Chlorella*-sp. tablets per day for four weeks, separated by twelve-week washout period. The saliva samples from the participants were collected before and after each trial and the saliva samples were obtained by a sterile cotton ball chewed by each participant. The study proved that salivary SIgA concentrations were significantly elevated after ingestion of *Chlorella*-sp. tablets compared to baseline ($P < 0.01$), which was not observed before and after placebo ingestion. The authors concluded that the **ingestion of a chlorella-derived multicomponent supplement increases salivary SIgA secretion and possibly enhances mucosal immune function** (Otsuki et al. 2011). In turn, Talbott et al. (2019) studied the effects of natural astaxanthin[3] (NAX), a pigment found in *Haematococcus pluvialis,* on the psychophysiological "heart-brain-axis" while nutrition (*Haematococcus pluvialis* algal

[3] Astaxanthins are multifunctional carotenoids usually obtained from *Haematoccocus pluvialis* – this microalga synthesizes astaxanthin in response to environmental stress (M. I. Khan, Shin, and Kim 2018).

extract) may impact physiology (cardiovascular function) and psychology (mood state) in a coordinated manner. 28 healthy subjects were supplemented for eight weeks with NAX (12 mg/day *H. pluvialis* extract) or a matching placebo. Before and after supplementation, participants performed a cardiovascular stress test and completed a validated Profile of Mood States (POMS) survey to assess global mood state (GM) and related subscales: Vigor (V), Tension (T), Depression (D), Anger (A), Fatigue (F), and Confusion (C). The individuals in the NAX group showed, not only a significant lower (approximately 10 %) average heart rate at submaximal exercise intensities when compared to those in the placebo group, but also a significant improvement of both positive mood state parameters – GM (+11 %) & V (+5 %) – and negative mood state parameters – D (-57 %), F (-36 %), C (-28 %), T (-20 %) & A (-12 %). Thus, the assay concludes that **natural astaxanthin supplementation supports the psychophysiological "heart-brain-axis" with simultaneous improvements in physical and mental wellness** (Talbott et al. 2019).

As well as seaweed, also microalgae have species that are used for human consumption. Therefore, the most used microalgae for human feeding are *Arthrospira* (*Spirulina spp*., a cyanobacteria), *Chlorella spp*., *Dunaliella salina* and *Aphanizomenon flos-aquae* (van der Spiegel, Noordam, and van der Fels-Klerx 2013). Regarding to the chemical composition of microalgae, typically they show a significant photoconversion efficiency, allowing them to accumulate high concentration of carbohydrates (usually more than 50 % dry weight). Carbohydrates have relevant biological functions in algal cells and the composition of storage carbohydrates is closely related to specie (Buono et al. 2014). The cultivation of microalgae was initially driven by its high content of high-quality proteins that could supply the needs of malnourished people in some developing countries. Most of microalgae contain essential amino acids that are not synthesized by human body, but can be obtained through the consumption of microalgae (Christaki, Florou-Paneri, and Bonos 2011). Three species are mostly used for protein production: *Chlorella*, *Spirulina* and *Dunaliella* (Buono et al. 2014). In terms of lipids, microalgae are a great source and a healthier alternative to fish, to obtain very high concentrations of long chain polyunsaturated fatty acids, such as eicosapentaenoic acid (EPA, 20:5, ω-3) and docosahexaenoic acid (DHA, 22:6, ω-3), that are the most interesting PUFAs as functional ingredients (Buono et al. 2014). Thus, microalgae are a valuable source of ω-3 PUFAs and, in fact, the genera and the species *Arthrospira*, *Chlorella*, *Dunaliella*, *Haematococcus*, *Schizochytrium*, *Porphyridium cruentum*, and *Crypthecodinium cohnii* have GRAS status (Caporgno and Mathys 2018). In the table 3 is presented the chemical composition – carbohydrates, crude protein, and lipids – of some edible microalgae. Nevertheless, microalgae are not only rich in macronutrients, but also in micronutrients which represent an important source for human nutrition. In this case, microalgae biomass can be a valuable source of all essential vitamins (A, B1, B2, B6, B12, C, E, nicotinate, biotin, folic acid and pantothenic acid) (Buono et al. 2014), as well as macro minerals (as Na, K, Ca and Mg) and microminerals (Fe, Zn, Mn and Cu) (Christaki, Florou-Paneri, and Bonos 2011). Also, microalgae are an incredible fount of pigments, such as chlorophylls, carotenoids, and phycobilins. Due to their ability to quenching the reactive oxygen species (ROS), acting as antioxidant molecules, carotenoids are used as bioactive ingredient in food, which also acts as a natural colouring agent. The major class of carotenoids includes β-carotene, astaxanthin, lutein, zeaxanthin, and canthaxanthin (Nethravathy et al. 2019). In fact, the main carotenoids produced by microalgae are β-carotene from *D. salina* and astaxanthin from *H. pluvialis* (Christaki, Florou-Paneri, and Bonos 2011).

Table 3. Chemical composition of some edible microalgae (% of dry matter) (Adapted from Christaki et al. 2011)

Species	Carbohydrates (%)	Crude Proteins (%)	Lipids (%)
Chlorella vulgaris	12-17	51-58	14-22
H. pluvialis	27	48	15
Dunaliella salina	14-18	39-61	14-20
Spirulina maxima	8-14	60-71	4-9
A. flos-aquae	23	62	3

Microalgae are an unquestionable sustainable solution to develop innovative functional food products due to the richness of their composition. In addition of the protein content and balanced amino acids profile, as already mentioned, microalgae incorporation into foods could bring a wide range of benefits to human health due to the presence of bioactive compounds (Caporgno and Mathys 2018). This incorporation can be as dietary supplements in the form of powder, capsule, pastille or tablet or also incorporated directly into foods, such as pasta, biscuits, bread, soft drinks, and others (Christaki, Florou-Paneri, and Bonos 2011). Moreover, microalgae showed some significant advantages compared to conventional land plants: they have much higher biomass productivities; low quality agricultural land is required for their cultivation; they use less water than terrestrial crops; several microalgae can be cultivated in brackish and sea water avoiding herbicide or pesticide application, and reducing the need of external nutrients (Buono et al. 2014). For example microalgae-based proteins needs < 2.5 m^2 of land per kg of protein while pork needs 47-64 m^2 and beef 144-258 m^2 (Caporgno and Mathys 2018).

1.4.3 Algae blends and their promise for food application

As already mentioned, both macro and microalgae have an enormous potential for application in different areas and markets. Due to its different constitution and properties, the combination of macro and microalgae in the formulation of blends could be an answer to the market requirements for new products that contain more and more functional and bioactive compounds. Thus, an algae blend can be a **mixture of different macroalgae**, a **mixture of different microalgae** or, even more interesting, a **mixture of macro and microalgae**.

Multiple studies have been performed to understand the potential effects and benefits of algae blends in different applications. Phycoremediation (Jasni et al. 2020), aquaculture feed (Schleder et al. 2020), cosmetics (Guillerme, Couteau, and Coiffard 2017), agriculture (Sarkar et al. 2018) and wastewater treatment (Hadi Abolhasani et al. 2019) are some of the areas where algae blends are being tested. The results of such applications are promising and are considered an open window for further investigation. Despite the multiple areas that are using algae mixtures, and considering the scope of this work, potential food applications with algae blends will be further discussed.

The seaweed Nori, also called red seaweed *Porphyra*, is widely consumed and, thus, there is an increasing demand for this alga, as already mentioned. Due to this fact researchers are evaluating the possibility of producing nori-like products but using other seaweeds. Erniati et al. have evaluated the chemical characteristics of a nori-like product produced by the mixture of *Gelidium sp.* and *U. lactuca*, named "geluring". Those researchers concluded that "geluring" had a high carbohydrate and dietary fiber contents and a low-fat content, having also important bioactive compounds, such as phenolics, as well as exhibiting antioxidant activity. These results show that **the mixture of seaweed has potential for being used as a functional food** (Erniati et al. 2018). Also, Abdulah et al. tried to obtain the most preferred nori-like product from a blend of *Gelidium sp.* and *Eucheuma cottonii* seaweed. It was elaborated mixtures of *Gelidium sp.* and *E. cottonii* 90:10 (%), 80:20 (%), 70:30 (%), 60:40 (%) and 50:50 (%). With the help of semi-trained panellists involved in preference tests, the **mixture of nori-like made with 70 % *Gelidium sp*. and 30 % *Eucheuma cottonni* was the most appreciated in the hedonic test** (a widespread rating scale that has been used for many years to collect data about the acceptance of food) (Abdulah et al. 2019).

Nevertheless, obtaining nori-like products it is not the only way to formulate algae blends – macroalgae, microalgae or macro and microalgae blends. In the next topic a market analysis of algae mixtures is explored.

1.4.3.1 Market analysis

In order to understand the market of algae blends, it is important to identify what types of edible algae blends are being currently commercialized, which brands produce these blends, which is the format of these blends, and which is their production country. Thus, a general market analysis elaborated with a basic search engine was performed (table 4).

Most of the analysed brands refer to their products (algae blends) as dietary supplement/ food supplement, organic superfoods/natural and organic products. These brands claim that the use of nutritional supplements is part of a balanced diet and of a healthy lifestyle. For maintaining optimal health, brands also claim that the daily consumption of these blends (in form of capsules, tablets, or powder) is recommended for improving body's nutritional profile once they contain essential nutrients that the body needs. Unfortunately, sometimes these essential nutrients cannot be obtained only through a balanced diet, especially in the case of people who have a frantic and stressful daily routine and who devalue mealtimes – for example, people eating their lunch quickly and consuming foods without nutritional value. Thus, the target customers are not only people that want to provide their bodies the best nutrients possible, but also people that are looking for quality supplements, offered by algae products, that are available for all diets (even vegan diets).

The brands represented in the table 4 use different channels to provide their products. Most products can be purchased through the company's website. Although some algae blends can also be acquired using large product sales platforms, as Amazon or Ebay, it is common to find these products for sale on online platforms of natural and niche products or even in local partners or shops.

Table 4. Market analysis of some brands that commercialize algae blends for human consumption

Commercialization Brand	Brand nationality	Company category *	Blend constitution	Blend format	Price **
Sunfood	USA	Medium-sized	Spirulina & Chlorella	Tablets	13.81 € (228 tb)
Microingredients	USA	No available	Spirulina & Chlorella	Tablets	24.84 € (720 tb)
Triquetra Health	USA	No available	Spirulina & Chlorella	Tablets	18.10 € (120 tb)
Health Food Monkey	UK	Micro	Spirulina & Chlorella	Tablets	4.53 € (no available)
Lucovitaal	Netherlands	No available	Spirulina & Chlorella	Tablets	14.99 € (200 tb)
Nature Love	Deutschland	Micro	Spirulina & Chlorella	Tablets	22.99 € (500 tb)
Natural Elements	Deutschland	Micro	Spirulina & Chlorella	Tablets	16.99 € (500 tb)
Nature Complete	UK	Micro	Spirulina & Chlorella	Tablets/Powder	22.87 € (180 tb or 90 g)
Chérie Sweet Heart	USA	No available	Spirulina & Chlorella	Tablets/Powder	9.14 € (228 tb) 20.25 € (454 g)
Moriah Foods	Canada	Medium-sized	Sea Moss, Dulse & Kelp	Powder	43.32 € (220 g)
Purasana	Netherlands	Small	*Aphanizomenon flos-aquae* (Klamath), Spirulina & Chlorella	Powder	19.55 € (200 g)
Revolution Foods	UK	Micro	Icelandic seaweeds	Powder	22.91 € (200 g)
Bareorganics	USA	No available	Kelp, Chlorella & Spirulina	Powder	23.04 € (227 g)
Beyond Fresh	USA	No available	Spirulina, Chlorella, Klamath & Dulse	Powder	23.96 € (180 g)
Algaessence	Portugal	-	*Chlorella vulgaris, Fucus vesiculosus* (bladderwrack) *& Ulva rigida*	Powder	10.44 € (100 g)
Aavalabs	Finland	Small	Spirulina & Chlorella	Capsules	19.49 € (200 cp)
Nested Naturals	Canada	Small	Spirulina & Chlorella	Capsules	15.63 € (120 cp)

Commercialization Brand	Brand nationality	Company category *	Blend constitution	Blend format	Price **
EmeraldIsle	Northern Ireland	No available	Bladderwrack, Sea spaghetti & Dulse	Capsules	19.43 € (90 cp)
The Really Healthy Company	UK	Micro	Chlorella, Spirulina & Klamath	Capsules	43.67 € (160 cp)
Vegavero	Deutschland	Small	Spirulina, Chlorella & *Ascophyllum nodosum*	Capsules	19.90 € (180 cp)
Nature's Sunshine	USA	Large	Chlorella, Spirulina & Klamath	Capsules	26.96 € (100 cp)
Swanson	USA	Large	Spirulina & Chlorella	Capsules	20.64 € (90 cp)
Power Organics	USA	Micro	Spirulina, Chlorella & Klamath	Capsules/Tablets/Powder	21.15 € (60 cp) 17.47 € (60 tb) 96.55 € (227 g)
Untamed Feast	Canada	Micro	*Macrocystis integrifolia, Alaria marginata & Laminaria saccharina*	Dried	7.84 € (20 g)
PORTO MUIÑOS	Spain	Small	Wakame, Nori & Sea lettuce	Dried	4.49 € (50 g)
Sea Spoon	UK	Micro	Dulse, Sea spaghetti & Sea lettuce	Fine flacks	6.82 € (30 g)

*** Staff headcount: < 10 Micro; < 50 Small; < 250 Medium; > 250 Large (source: European Commission – Entrepreneurship and SMEs)**
**** tb (tablets); g (grams); cp (capsules)**

1.5 Technology Surveillance

Technology advancements have been promoting the development of new markets that are becoming increasingly global. Despite the large volume of data currently available to organizations, those need to be able, not just to collect relevant information, but also to interpret that information to make quicker decisions in order to benefit from market opportunities. In addition, the increasing competitiveness of markets, as well as the constant pressure faced by companies due to economic, political and social conditions have led to the development of competitive strategies and tools aiming at identifying technology breakthroughs and market trends (Augusto and Alexandroni, n.d.).

Technology surveillance (TS) is a relevant tool to detect opportunities for technological innovations and new ideas that enable the improvement of processes, products and organization's services (OVTT n.d.). In other words, the TS encompasses the permanent collection, organization, and selection of information about a target technology. It also includes the analyses of information in order to convert it into knowledge useful to support the decision making process related to innovation, and thus decreasing the risk of the process itself by anticipating changes (Augusto and Alexandroni, n.d.). The gathering of information is based on patent documents, academic publications and investigation (Junior 2014). In fact, 70 % of the literature about a specific technology is codified in patents. Therefore patents are one of the most important sources of information to perform a technology surveillance (OVTT n.d.).

The process of technology surveillance can be divided into 5 major steps (Augusto & Alexandroni, n.d.; Junior, 2014; OVTT, n.d.-a) (Fig. 2):

1. **Identification** of target organization's needs;
2. **Research** and **gathering** of information;
3. Information **analysis**;
4. **Valuation** of the information;
5. **Disseminate/Spread** the information.

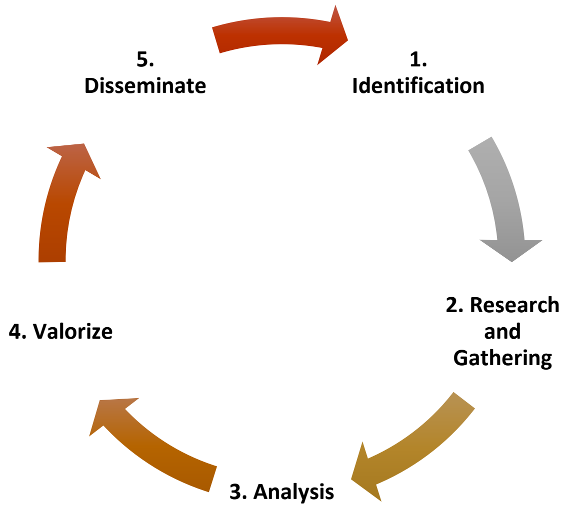

Figure 2. Schematic cycle representation of the principal steps for technology surveillance process

In the **identification** step, the organization needs to identify pertinent information through self-diagnosis, that will allow to detect and specify the theme/topic that the organization will monitor. In this case, current company's technological context, information about suppliers, competitors and customers must be considered. In the phase of **research** and **gathering** of information, the goal of the information search is defined, and a strategy is elaborated in order to specify the needs, locate the information, and gather the information in an organized manner. Information **analysis** step allows to process and filtrate the relevant collected data through a combination of validation criteria, analytic techniques and informatic tools. In the **valuation** of the information, "products" are elaborated from the obtained results. Those products can be, for example, a Technological surveillance bulletin or a report. The **Disseminate/Spread** of information is an important step once it will disseminate the results obtained from the technology surveillance to those who have relevant responsibilities within the organization. An intern communication strategy must be delineated (Junior, 2014; OVTT, n.d.-a).

Technology Surveillance brings several benefits and advantages for an organization, such as: **anticipation**, in order to detect changes (new technologies, new products, competing or niche markets); **risk reduction**, by detecting threats (patents, new investments, coalition between companies); **progress** (time lag between products' development and customer needs' identification); **innovation** (detect new ideas and solutions); **cooperation** with new partners, customers or specialists; a better **knowledge** of the company itself (strengths, weaknesses; technology capabilities); affordable **cost** and fast and easy **access** (Mata 2004). However, TS can entails some difficulties that latter become a disadvantage, such as the usual confusion between the term TS and industrial espionage: technology surveillance only works with information obtained from legal means, unlike espionage. Also, the gathering of information and its analyses could be a hard task due to the quantity of information (Carlos Fonseca dos Reis 2008).

Despite **Technology Surveillance** and **Competitive Intelligence** (CI) being the two central tools aiming at obtaining precise and up-to-date information, TS and CI have different applications. The Competitive Intelligence is considered one more step of the information management process which is included in the Technology Surveillance analysis (Augusto and Alexandroni, n.d.). In other words, while the TS collect, analyse and disseminate useful information, the CI exploits the use of that information in an accurate way to help in the decision making process (Junior 2014).

1.6 Technology Forecasting

Technology forecasting (TF) can be defined as "the systematic process of describing the emergence, performance, features or impact of a technology at some time in the future" (Bildosola et al. 2018, p. 1). With the advances in information technologies and the rapid rate of technological and societal changes, there is a growing demand for TF approaches in companies' management. Therefore, public and private sector entities are increasingly applying TF from regional to global levels to gain competitive advantage, create social change, implement regulation, among others (Behkami and Daim 2012).

The traditional method to identify and forecast technological trends is based on the experience of specialists, which is a long and costly procedure and affected by subjective factors. Nowadays, due to the existence of a large volume of technical data – scientific papers, patents, and others – researchers have begun to use not only that information, but also quantitative approaches to analyse and study technology trends

(Li et al. 2019). These quantitative approaches include, most of the times, **bibliometric analysis** and **text mining method** (Coates et al. 2001).

Bibliometrics is the quantitative statistical analysis of written publications, such as articles or books (Muslu 2018). Bibliometric studies allow the comparison of numerous topics between countries, institutions, or authors through the analyses of specific characteristics of documents/publications (attributes or metadata of these documents/publications, such as titles or authors and their affiliations, keywords, sources or references (Wang et al. n.d.)) to obtain applicable/relevant findings for scientific communication (Demir et al. 2020). Therefore, bibliometric analysis is an efficient tool for identifying research trends in various scientific disciplines (Vakilian, Yeop Majlis, and Mousavi 2015). **Text mining** is a knowledge based process that uses analytical tools to obtain significant and meaningful information from a natural language text (Abbas, Zhang, and Khan 2014). Therefore, text mining tools help to evaluate a large dataset of information of a technology domain and assist in decision-making in different matters, as top countries in the respective technological domain (Vincent et al. 2017). While **bibliometrics** focuses on measurement of scientific activity to find patterns and trends, **text mining** goes beyond processing the content of publications (Bildosola et al. 2018).

1.7 Patent Analysis

Patent analysis techniques are widely used for different purposes. The growing interest in patent analysis is related with: (1) patent trend analysis; (2) analysis of the density of patent filings of a specific technology; (3) competitive analysis; (4) forecasting technology developments/innovation patterns; (5) determining patents quality analysis for R&D tasks; (6) strategic technology planning; (7) identification of technological vacuums and hotspots (Shalaby and Zadrozny n.d.; Cho et al. 2018; Abbas, Zhang, and Khan 2014).

Patents provide complementary information in literature bibliometric analysis due to their valuable information content (Y. Cho and Daim 2013). The task of analysing patent data to promote patent intelligence, using automated tools such as visualization, citation analysis, text mining and others, is termed patent informatics (Singh, Chakraborty, and Vincent 2016). For patent analysis, **visualization techniques** are widely used once they create visual representations of patent information and analysis outcomes (Jui, Trappey, and Fu 2016). Patent maps or clustering methods can be utilized to understand the technological trends in a particular domain. It is important to note that even though visualization techniques display visually the information obtained from the patent, they still use certain text mining approaches to extract some information from a document (Abbas, Zhang, and Khan 2014).

Patents contain several items useful for analysis which can be grouped into two categories (Abbas, Zhang, and Khan 2014; Choi and Hong 2020):

- **Structured data:** is the information that appears on the first page of a patent document, such as the inventor of the patent, assignee of the patent, citation information, filling date, etc;
- **Unstructured data:** that includes content of different structures and styles, comprising narrative text, such as the abstract, claims and description.

Text mining deals with extracting valuable patterns mostly from unstructured data rather than structured data, while visualization techniques are more applicable for structured data (Abbas, Zhang, and Khan 2014).

There are two primary ways of analysing patent information: **quantitative** and **qualitative approaches** (Hong 2007). Quantitative methods of patent analysis involve statistical analysis of patent information, which means that the analysis is derived from statistical assessment of patent bibliographical information, such as assignees, number of patent applications, etc. In turn, qualitative methods assesses the content of a patent and its technical information using matrix or tree diagrams (Jui, Trappey, and Fu 2016), through the establishment of inter-relationships between patents' content (WIPO n.d.). These two ways of analysing patent information can be complementary. For example, patent maps may integrate quantitative and qualitative analyses of patent documentation for domain-specific technologies (Jui, Trappey, and Fu 2016).

There are different methodologies to analyse the information of patent documents, but usually it comprises a set of steps, such as (1) extracting patent documents, related to a target technology, from patent databases; (2) extracting the relevant information from the patents; and (3) analysing the extracted information to make inferences and draw conclusions (Abbas, Zhang, and Khan 2014; Jun 2015).

1.7.1 Indicators in Patent Analysis

The establishment of indicators is useful when performing a patent analysis since those, together with patent valuation, are crucial to design a probabilistic assessment approach for different purposes, such as the identification of technology trends, and detection of emergent technologies, for a better decision-making process (Lumpur et al. 2010).

According to the Organisation for Economic Co-operation and Development (OECD) there are, mainly, three types of patent-based indicators: Citation-based; Indicators of Internationalization of Science and Technology and Indicators of Patent Value (OECD 2009).

1.7.1.1 Citation-based Indicators

There are two groups of indicators within citation-based indicators: backward citation indicators and forward citation indicators (Lumpur et al. 2010).

Backward citation indicators evaluate the degree of invention's novelty and knowledge transfer patterns. Examples are: Technological cumulativeness (frequency of self-citation of patents produced by a company's prior research); Citation lags (time passed between the publication of the application and the first forward citation it receives; a shorter citation lag can be associated with a higher patent value); Technology cycle time (TCT) (median age in years of patent references cited on the front page of a company's patents; TCT indicates speed of innovation, an higher TCT represents a great technological advantage) (OECD 2009; Choi and Hong 2020; Fisch, Sandner, and Regner 2017).

Forward citation indicators measure the technological impact of inventions, once they refer to the number of times a patent has been cited by subsequent patents.

There are indicators relevant to the patent level or to the portfolio level. Examples of indicators relevant for patent level are: Citation Index (count of the citations received by a company's patents from subsequent patents); Forward Citation Frequency (number of forward citations received by a patent per year). This is an indication of the impact of a company's patents; Generality (indicates the diversity of citing patents, i.e. the patents that cite the target patent). Examples of indicators relevant for portfolio level can be: Current Impact Index (CII) (the number of times a company's previous five years of patents are cited in the current year; indicates patent portfolio quality); Technology strength (indicates quality-weighted portfolio size or, in other words, patent portfolio strength) (OECD 2009; Fisch, Sandner, and Regner 2017; Aristodemou and Tietze 2018)

1.7.1.2 Indicators of Internationalization of Science and Technology

Inventions made by researchers residing in one country can be funded and owned by foreign companies. Also, companies from different countries can join their resources to sponsor research, as well as researchers from different countries can co-operate on inventions, and so on. For those reasons, different indicators are available to measure the internationalisation of science and technology (S&T). The indicators can be divided in two groups: cross-border ownership of inventions and international co-operation in research. The **cross-border ownership of inventions** considers the indicators applied to applicants and inventors whose country of residence differ, indicating cross-border ownership. The indicators from **international co-operation in research** specifies a measure by patents involving inventors from a different country of residence. (OECD 2009)

1.7.1.3 Indicators of Patent Value

The term "patent value" has several different meanings. On the one hand, it can mean the economic "private" value to the holder (value added by the fact that the invention is patented) or, on the other hand it can mean the "social" value of the patent ("quality" of the invention). Despite the value of a patent be a complex notion, it is necessary to take it into account for patent statistics. Indicators of Patent Value vary greatly in the information they give us. Examples are: Forward citations have also been found to be strongly associated with the economic value of patents (inclusively, the number of forward citations is one of the most recurrently used value indicators); Number of inventors (cost of research; cost of an invention); Renewals (cost of maintaining a patent) and Patent Family Size [4] (refers to the number of countries in which an invention is protected by a patent); Triadic Families (indicates patents for which the same invention, same inventor, or applicant applied to United States Patent and Trademark Office's (USPTO), Japan Patent Office (JPO), and European Patent Office (EPO) at same time). (OECD 2009; Kabore and Park 2019; Kim and Bae 2017)

[4] The term "patent family" apply to a collection of patents that refer to the same invention and are granted at different countries around the world (Shalaby and Zadrozny n.d.). A patent family contains all those patent documents which refer exactly to the same technical topic (Michel and Bettels 2001).

2. Methodology

2.1 Patent Analysis

2.1.1. Considerations about Intellectual Property

According to The World Intellectual Property Organization (WIPO), Intellectual property (IP) refers to creations of the mind: inventions; literary and artistic works; symbols, names, images and designs used in commerce (World Intellectual Property Organization 2016). IP is divided into two categories according to the World Intellectual Property Organization (2016):

I. **Industrial Property**: that includes patents for inventions, trademarks industrial designs and geographical indications;
II. **Copyright**: that includes literary, music, films, artistic works, and architectural design.

Thus, a **patent** is a legal intellectual property protection document (César et al. 2017) that gives an exclusive right granted for the production and commercialization of an invention (a product or a process) for a limited period, usually 20 years (World Intellectual Property Organization 2016). Before a patent on an invention is obtained there are a set of requirements that needs to be meet (WIPO 2004):

a. It must be new (**novel**)
b. It must exhibit an inventive step (be **non-obvious**)
c. It must be industrially applicable (**useful**)

The patent is commonly viewed as an important instrument for the development of the world's economy since it is essential to protect high-tech investments. More than 170 countries are members of the Paris Convention [5] and among these countries more than 140 have approved the Patent Cooperation Treaty (PCT) [6] (Nielsen et al. 2010).

[5] International Agreement (adopted in 1883): applies to industrial property in the widest sense and the repression of unfair competition. (Source: https://www.wipo.int/treaties/en/ip/paris/)

[6] Assists applicants in obtaining patent protection internationally for their inventions; helps patent offices with their decisions; enables public access to a variety of technical information relating to those inventions. (Source: https://www.wipo.int/pct/en/)

The introduction and promotion of a patent system has been motivated by some reasons:

- Reward the inventor(s) with a time-limited monopoly to ensure that commercial exploitation of an invention by others rather than the patent owner is prohibited (Nielsen et al. 2010);
- Encourages the commitment of additional resources for further innovation (World Intellectual Property Organization 2016), since legal protection acts as a kind of "safe haven" that promotes R&D;
- Stimulates economic growth, creates new jobs and industries (World Intellectual Property Organization 2016);
- Promotes the discovery of valuable information, that might otherwise have been kept secret (Nielsen et al. 2010).

However, some potential disadvantages are also associated with the patent system. Examples are: high costs and resources related to patenting process or trials and trial-risk due to the possible infringement of patents of others (Szűcs 2015).

Patent documents are generally textual, being highly structured with elements that are characteristic, including *title*, *abstract*, *background of the invention*, *description* and *claims* (Shalaby and Zadrozny n.d.). Important information such as Priority Date, name(s) of Inventor(s), Assignee(s) name(s) and International Patent Classification (IPC) are also included in the document (Hoeltgebaum, De Souza Vieira, and Martins 2016). The **Priority Date** notifies when the invention was submitted for the first time, counting all the rights for the idea from this date; **Inventor(s)** is the person (or group of persons) who developed the invention; **Assignee(s)** is who will detain the rights of application of a given patent (the own inventor; a company or an institution); **IPC** is a code (with 8 digits) mixing numbers and letters that classifies the patents; the **Descriptions and Drawings** allow the designer to obtain details about the technology; **Claims** are the most important part once it is exactly what the inventors and assignees want to protect (Hoeltgebaum, De Souza Vieira, and Martins 2016). The advantages of analysing patent documents include the international standardization of the layout specification (described above), as well as the possibility of statistical treatment of the data, and the detailed/complete descriptions of the inventions – making them appropriate for different analysis, as market analysis (Mendes et al. 2019).

There are several routes to obtain patent protection concerning a specific invention (OECD 2009). The route chosen depends on the overall strategy of the inventor of the patent application. But first, it becomes important to distinguish a “patent” from a “patent application”. A **patent** is an issued right which is obligatory in the state in which it is granted. However, a **patent application** is just an application which might end up being abandoned, refused or, in the best case, granted with its original or restricted scope (Nielsen et al. 2010). Thus, patent applications may be filed nationally, regionally or as an international patent application:

- **National route:** The national route occurs when the inventor decides to protect its invention nationally (generally the national office of the applicant’s country). For that, the inventor needs to file the first application, so-called priority application – note that priority applications at a later stage are used to claim priority date. The application is normally published 18 months after it is filed, which also means 18 months after the priority date. The time between filing and grant or refusal of a patent is not fixed, varies from two to eight years (Nielsen et al. 2010; OECD 2009).
- **Regional route:** Applicants submit the patent application to a regional office, such as the European Patent Office (EPO). Currently, EPO, which grants European patens, is a regional office with 38 members (EPO n.d.) (Fig. 3). The validation in all member states of Europe requires translation into the national language and payment of national costs (OECD 2009).
- **International route:** Applicants who wish to protect their invention in more than one country have two options: or the applicants have 12 months from the priority date to file applications in other Convention Countries or applicants use the **PCT**. The PCT route includes filling of one or more priority applications which within one year is followed by a PCT application. However, the international application terminates

30 months after the priority date. After that, the PCT application is converted into a series of national and regional patent applications, since an international or world patent designation does not exist. So, during the delay until the thirtieth month the applicants have some advantages such as more time to fulfil national requirements and exploit the invention. These gains make the PCT route the most popular and used route (Nielsen et al. 2010; OECD 2009) .

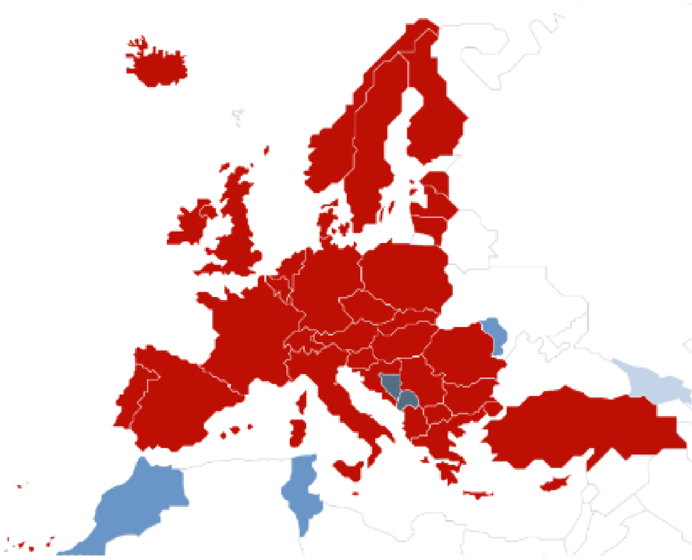

Figure 3. Map showing the geographic coverage (in red) of European patents in 2019 (Source: https://www.epo.org/about-us/foundation/member-states.html)

As already mentioned, after 18 months from the priority date the patent application is published. The patent publication has important functions, such as to define the invention for which the applicant searches protection; communicate technical or scientific information valuable for the community and it is a barrier to the later patenting by competitors (Nielsen et al. 2010). In this work we used Questel – Orbit Intelligence ® to search/identify patents concerning seaweeds and microalgae applications and technological features.

2.1.2 General considerations about Questel – Orbit Intelligence ®

The structured and unstructured data of seaweed were analysed using the **Orbit Intelligence ®** (Questel) software. This program was used because provides data mining tools to analyse individual databases with unique features for creating database clusters and combine them into a single one (Vincent et al. 2017). Questel besides covering more than 100 patent authorities and the applications of more than 50 countries, it provides duplicate free results and it is updated daily (Villela et al. 2019). Also, the software enables the search within three main collections: Fampat; Fullpat and Fulltext (Questel 2017).

The patent documents were grouped into FamPat patent families, which include documents that are believed to cover the same invention – one record per patent invention. This grouping is automatically made by Orbit Intelligence and cover several stages of an application in a given country or related applications that are filed in different countries (Machado-Silva et al. n.d.).

2.1.3 Patent data compilation

The tool Advanced Search was used to generate the data. The search was performed in different steps in order to obtain different and segmented data, allowing to analyse the seaweed and microalgae market in detail.

A. Macroalgae

First, an initial search was made using the following keywords: **Seaweed OR Macroalgae OR Marine algae** in four fields: title, abstract, claims and description. The legal status was filtered as “Alive”. Next, the search was restricted just to granted patents and, later, the pending patents were also consulted to analyse the future trends. In table 5 the commands used through the different steps of the search are presented.

In order to assess the case of the **Portuguese** seaweed market, a research was performed using seaweed keyword with the legal status as “Alive”, and the field “Assignee Country” selected as Portugal (PT) (Table 5). In each search, Orbit Intelligence generate a list of all the patent families that match with the entry commands. These outputs allowed to access several data such as the technology domains, key players, key countries, and others.

Table 5. Example of the search commands performed on Orbit Intelligence for the case of seaweed in general

	STEP	COMMAND
SEAWEED	1	**Seaweed OR Macroalgae OR Marine algae/** Field: Title, Abstract, Claims, Description / Legal Status: **Alive**
	2	**Seaweed OR Macroalgae OR Marine algae/** Field: Title, Abstract, Claims, Description / Legal Status: **Alive** / **Granted**
	3	**Seaweed OR Macroalgae OR Marine algae/** Field: Title, Abstract, Claims, Description / Legal Status: **Alive** / **Pending**
PORTUGAL	1	**Seaweed OR Macroalgae OR Marine algae/** Field: Title, Abstract, Claims, Description / Legal Status: **Alive**
	2	**Seaweed OR Macroalgae OR Marine algae/** Field: Title, Abstract, Claims, Description / Legal Status: **Alive** / Assignee Country: **PT**

Then, a search was performed taking into count the classification of the seaweed associated with their pigmentation. Thus, three dominations were searched: **Brown algae OR Brown seaweed**; **Green algae or Green seaweed**; **Red algae OR Red seaweed**. The selected fields and filters applicate to the search were the same as the ones mentioned above (excluding the Assignee Country).

The data and respective results were obtained in a single day (21/01/2020) for each portfolio, so that the Orbit would not be able to actualize the data and consequently the results.

B. Microalgae

The procedure steps for the patent data collection used for microalgae was the same used for seaweed – see table 6. The data and respective results were obtained in a single day (02/06/2020).

Table 6. Example of the search commands performed on Orbit Intelligence for the case of microalgae

	Step	**Command**
Seaweed	**1**	**Microalgae OR Microalga/** Field: Title, Abstract, Claims, Description / Legal Status: **Alive**
	2	**Microalgae OR Microalga/** Field: Title, Abstract, Claims, Description / Legal Status: **Alive** / **Granted**
	3	**Microalgae OR Microalga/** Field: Title, Abstract, Claims, Description / Legal Status: **Alive** / **Pending**
Portugal	**1**	**Microalgae OR Microalga/** Field: Title, Abstract, Claims, Description / Legal Status: **Alive**
	2	**Microalgae OR Microalga/** Field: Title, Abstract, Claims, Description / Legal Status: **Alive** / Assignee Country: **PT**

2.2 Bibliometric Analysis

2.2.1 General considerations about VOSviewer

VOSviewer [7] software enables the construction and visualization of **bibliometric networks**. The software provides three visualizations typologies: the network visualization, the overlay visualization, and the density visualization. In the **network visualization**, items (the objects of interest – publications, researchers, etc.) are represented by their label and by default also by a circle. The size of the circle of an item is determined by their weight that indicates the importance of an item – higher weight more prominently the label and higher the circle. Each link (connection or relation between two items) has a strength, represented by a positive numerical value. The higher this value, the stronger the link. Colours and lines are also expressed in the map. The colour of an item is determined by the cluster (set of items included in a map) to which the item belongs and the lines between items represent links. In the **overlay visualization** items are coloured differently and have a score associated, being the colour of an item determined by the score of the item – by default colours range from blue (lowest score) to green to yellow (highest score). There are two variants of the **density visualization**: Item density and Cluster density. The item density is similar with network and overlay visualization and by default, colours range from blue to green to

[7] All the information and explanations presented in the topic "General considerations about VOSviewer" were obtained from the VOSviewer Manual: (van Eck and Waltman 2020)

yellow (the larger the number of items in the neighbourhood of a point and the higher the weights of the neighbouring items, more yellow is the point). In the cluster density the density of the items is displayed separately for each cluster of items and the colour of a point is the result of the mixing of the colours of different clusters.

To create a new map based on bibliographic data, different analysis and items can be selected. In the table 7, a summary of the main options provided by the software to analyse bibliographic data is presented.

Table 7. Type of Analysis and respective possible units of analysis for bibliographic data.

TYPE OF ANALYSIS (LINKS)	UNIT OF ANALYSIS (ITEMS)
CO-AUTHORSHIP	Authors Organizations Countries
CO-OCCURRENCE	Keywords
CITATION	Documents Sources Authors Organizations Countries
BIBLIOGRAPHIC COUPLING	Documents Sources Authors Organizations Countries
CO-CITATION	Cited References Cited Sources Cited Authors

2.2.2 Four main steps of the methodology used

In order to elaborate a case study about the research trends in macro and microalgae in the food sector, the four main steps proposed by Milanesi et al. (2020) were followed, namely planning, searching, screening, and extraction/synthesis/reporting (Milanesi, Runfola, and Guercini 2020). The methodology and data analysis were performed on the 6th of July 2020.

I. *Planning*

The first step of the procedure suggests limiting the focus of the review by discussing the research questions. Thus, two major questions were defined:

1. What is the current status of research on macro and microalgae food industry?
2. What are the future trends that will mark the macro and microalgae food sector?

II. *Searching*

For the search stage, the Web of Science (WoS) database was adopted as the data source. The search was divided in two major researches: **macroalgae** and **microalgae studies**. For both studies, the initial keyword search in WoS was limited to "Title, Abstract, Author Keywords, Keywords Plus® [8]). Macroalgae keyword search included: (macroalgae OR seaweed) AND (food OR "human nutrition"). Microalgae keyword search included: microalgae AND (food OR "human nutrition").

The documents published between 2000 and 2020 were used to analyse results directly from WoS, for macro (3510 publications) and microalgae (3332 publications). However, to analyse the bibliographic data with VOSviewer only the documents published between 2017 and 2020 were extracted (1351 publications for macroalgae and 1442 publications for microalgae).

[8] Index terms automatically generated from the titles of cited articles; only available in WoS. (Source: https://images.webofknowledge.com/images/help/WOS/hp_full_record.html)

III. Screening

The researches followed certain inclusion, and consequently exclusion, criteria to select papers for in-depth analysis through the data source WoS and VOSviewer software (Table 8).

Table 8. Inclusion criteria used for WoS and VOSviewer and respective number of documents

TOOL	ASPECT	INCLUSION CRITERIA	NO. DOCUMENTS
WOS	*Subject area*	Food Science Technology and Nutrition Dietetics	Macroalgae: 731 Microalgae: 376
	Document type	Article and review	Macroalgae: 713 Microalgae: 367
VOSVIEWER	*Subject area*	Food Science Technology and Nutrition Dietetics	Macroalgae: 317 Microalgae: 211
	Document type	Article and review	Macroalgae: 309 Microalgae: 205
	Language	English	Macroalgae: 306 Microalgae: 202

IV. Extraction, Synthesis and Reporting

The data taken from the WoS were analysed with the help of the own platform and with VOSviewer. A more descriptive analysis was performed using WoS, where publications by year; top 10 publisher countries; top 10 publisher sources and top 10 most cited documents were performed for both algae studies.

Using VOSviewer two types of analysis were executed: co-authorship analysis and co-occurrence analysis. For both types of analyses some restrictions were required, such as i) for the co-authorship analysis the minimum number of documents of an author/organization/country was 2 authors and 3 organizations or countries, and ii) for the co-occurrence analysis, the minimum number of occurrences of an author keyword was 4. Also, for the co-occurrence analysis the keywords “macroalgae”, “seaweed”, “seaweeds” and “microalgae” were excluded, as well as non-sense keywords.

3. Results and Discussion

3.1 Patent Analysis

3.1.1 Patent Data Mining

3.1.1.1 Macroalgae

The search of patent portfolios related to seaweed resulted in 49582 patent families with **Seaweed OR Macroalgae OR Marine algae** in the title, abstract, claims and description. From those patent families, 27696 are granted and 27441 are pending (of which 5555 patent families are pending in some countries and already granted in others).

The top five IPC codes listed on the alive patent families (granted or pending) are: A61K 08/00 in 6820 patents, A61Q 19/00 in 5046 patents, A61K 31/00 in 4656 patents, A61K 36/00 in 4124 patents and A23L 33/00 in 3834 patents. On the table 9, the top five IPC codes and respective description, number of family patents and top ten concepts are presented. Analysing the table 9 it is evident that the IPC codes related to the health and beauty care are the most mentioned, such as the A61K 08/00 or A61Q 19/00.

In the case of **Portugal**, it was found 29 patent families with Portuguese assignees that detain all the rights of a given patent. In other words, 29 patent families related to **seaweed** have a Portuguese inventor, are from a Portuguese company or are from a Portuguese institution, being 19 granted and 21 pending (of which 11 are granted in some countries and pending in others). The top five IPC codes are: A61K 09/00 in 8 patents, A61K 47/00 in 6 patents, C12P 19/00 in 4 patents, A23K 10/00 and A61K 38/00 both in 3 patents. The A61K 09/00 is related with medical preparations characterised by special physical form; A61K 47/00 is related with medical preparations characterised by the non-active ingredients used; C12P 19/00 refers to preparation of compounds containing saccharide radicals; A23K 10/00 covers animal feeding-stuffs and A61K 38/00 is associated with medical preparations containing peptides. Thus, by the results it is observable that in Portugal new inventions are mainly in areas related to medical preparations.

Table 9. Top five IPC codes for seaweed data and related information

IPC CODE	DESCRIPTION	NO. OF FAMILY PATENTS	TOP 10 CONCEPTS
A61K 08/00	Cosmetics or similar toilet preparations	6820	Seaweed extract (2356); Arbutin (1398); Aloe extract (1384); Mink oil (1330); Algae extract (934); Saxifrage extract (863); Rice germ oil (756); Horse chestnut extract (751); Peony extract (722); Gentian extract (606)
A61Q 19/00	Preparations for care of the skin	5046	Seaweed extract (1884); Arbutin (1146); Aloe extract (1130); Algae extract (772); Saxifrage extract (665); Horse chestnut extract (619); Rice germ oil (614); Peony extract (574); Gentian extract (484); Arnica extract (468)
A61K 31/00	Medical preparations containing organic active ingredients	4656	Active ingredient (2306); Excipient (1750); Sodium alginate (952); Carrageenan (934); Guar gum (777); Anti-inflammatory agent (658); Seaweed extract (603); Seaweed (556); Carotenoid (511); Dietary supplement (504)
A61K 36/00	Medical preparations of undetermined constitution containing material from algae, lichens, fungi or plants, or derivatives thereof, e.g. traditional herbal medicines	4124	Seaweed (1238); Seaweed extract (727); Extract (631); Alginic (425); Licorice extract (383); Marine algae (322); Algae extract (299); Aloe extract (288); Spirulina seaweed (245); Facial cleanser (238)
A23L 33/00	Modifying nutritive qualities of foods; Dietetic products; Preparation or treatment thereof	3834	Seaweed (832); Spirulina seaweed (475); Kelp (445); Spirulina (382); Seaweed extract (321); Seaweed powder (314); Marine algae (282); Seaweed polysaccharide (254); Spirulina powder (203); Porphyra Purpurea (193)

The search performed using **Brown algae OR Brown seaweed** found 7686 patent families of which 4801 are granted and 2885 are pending. In turn, using the keywords **Green algae OR Green seaweed** found 11225 patent families were found, of which 6846 granted and 4379 pending. Lastly, for the **Red algae OR Red Seaweed** the number of patent families obtained was 7461, of which 4870 patent families were granted and 2591 were pending. The green algae are the most explored macroalgae, once the search indicate the highest number of patent families.

3.1.1.2 Microalgae

For the case of microalgae portfolio, the search result in a total of 12524 alive patent families. From those patent families, 7544 patents are granted and 6727 are pending (of which 1747 are granted and pendent at the same time).

The top five IPC codes of the alive patent families are: C12N 01/00 in 3472 patents, C12M 01/00 in 2154 patents, C12R 01/00 in 2100 patents, C12P 07/00 in 1606 patents and C12N 15/00 in 1353 patents. As in the portfolio of macroalgae, the table 10 indicates the top five IPC codes and respective description, number of family patents and top ten concepts for microalgae portfolio. Through the examination of the table 10, it is possible to affirm that microbiology, enzymology, and genetic engineering are the dominant study areas for the mentioned IPC codes.

Table 10. Top five IPC codes for microalgae data and related information

IPC CODE	DESCRIPTION	NO. OF FAMILY PATENTS	TOP 10 CONCEPTS
C12N 01/00	Microorganisms; Compositions thereof; Processes of propagating, maintaining, or preserving microorganisms or compositions thereof; Processes of preparing or isolating a composition containing a microorganism; Culture media thereof	3472	Microalgae (1683); Microalga culture (850); Microalgae growth (618); Microalgae cultivation (544); Culturing microalgae (468); Microalgae cell (433); Microalgae biomass (389); Microalgae species (332); Microalgae production (323); Microalgae culture medium (271)
C12M 01/00	Apparatus for enzymology or microbiology	2154	Microalgae (1170); Microalgae culture (760); Photobioreactor (609); Microalgae cultivation (520); Microalgae growth (467); Culturing microalgae (348); Closed photobioreactor (199); Photosynthetic microalgae (169); Raceway pond (148); Light bioreactor (135).
C12R 01/00	Microorganisms	2100	Microalgae (1009); Microalgae culture (559); Microalgae growth (404); Microalgae cultivation (370); Algae broth (328); Microalgae cell (290); Culturing microalgae (261); Microalgae biomass (241); Microalgae culture medium (196); Alga strain (188)
C12P 07/00	Preparation of oxygen-containing organic compounds	1606	Microalgae (768); Centrifugation (707); Culture medium (674); Culture (577); Fatty acid (559); Biomass (527); Biodiesel production (451); Polyunsaturated fatty acid (443); Biodiesel (404); Lipid production (339)
C12N 15/00	Mutation or genetic engineering; DNA or RNA concerning genetic engineering, vectors, e.g. plasmids, or their isolation, preparation, or purification; Use of hosts thereof	1353	Gene (593); Amino acid sequence (539); Host cell (474); Expression vector (468); Sequence identity (445); Gene encoding (442); Microalgae (437); Nucleic acid sequence (416); Homologous recombination (404); Constitutive promoter (360)

For the Microalgae **Portuguese** portfolio, it was found 15 patent families: being 9 granted and 9 pending (of which 3 are granted in some countries and pending in others). The top five IPC codes are: A23K 10/00 and C12N 01/00 in 3 patents and A23K 50/00, C02F 01/00 and C02F 03/00 in 2 patents. The IPC code A23K 10/00 is related with animal feeding-stuffs; C12N 01/00 was already described (see table 10); A23K 50/00 is related with feeding-stuffs specially adapted for particular animals; C02F 01/00 associated with treatment of water, waste water, or sewage and, at last, C02F 03/00 related with biological treatment of water, waste water, or sewage.

3.1.2 Patenting trends in Algae technological domains

For further analysis it was used the Orbit chart tools that allow the analysis of relevant information to the study of the patenting trends and technological domains. All searched data was related to the last two decades, which means that the analysed data includes the year 2000 and the following twenty years as a possible first application year.

3.1.2.1 Macroalgae

Through the data obtained that covered the period 2000-2020, the year 2017 was the "first application year" with the highest number of patent families (alive) accounting for 7388 patents. In turn, 2000 was the year with the lowest number of submissions with just 491 patent families. Additionally, 2019 was the year with the smallest number of patent families submitted since 2012, with only 2412 submissions of applications, this can be indicative of the decrease of the seaweed market exploration or by the fact that the application were not published yet. China is the country with the biggest slice of the seaweed portfolio, detaining 33.84 %, equivalent to 21505 patent families.

Examining the top 10 assignees (detaining only 4 % of all patent inventions), KAO, a Japanese company, is the major key player with a total of 358 patent families, of which 295 are granted and 63 are pending. Zhejiang Ocean University is the assignee with most pending patents, demonstrating the Chinese research and development in seaweed sector (Fig. 4).

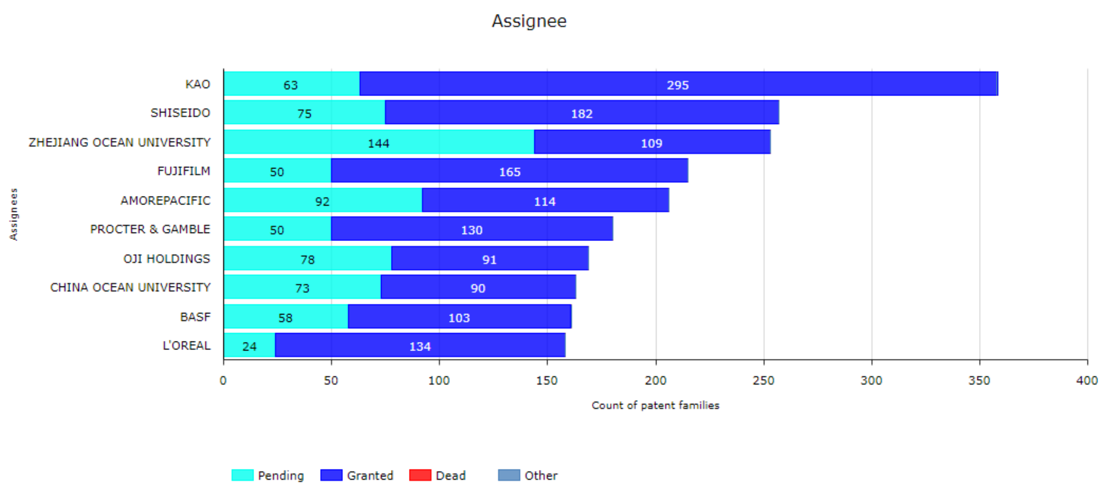

Figure 4. Top 10 key players and respective patent families with legal status for the seaweed portfolio

The technology domains based on the IPC codes contained in patent set analysed are presented in the Fig. 5. It is noticed that Food chemistry is the main technology domain, with a large notorious margin (14702 patents). Organic fine chemistry, Pharmaceuticals and Basic materials chemistry are also technology domains with a lot of aggregated patent families, correlated with seaweed. A patent can have more than one technology domain related, giving rise to a large amount of patent families for a certain technology domain.

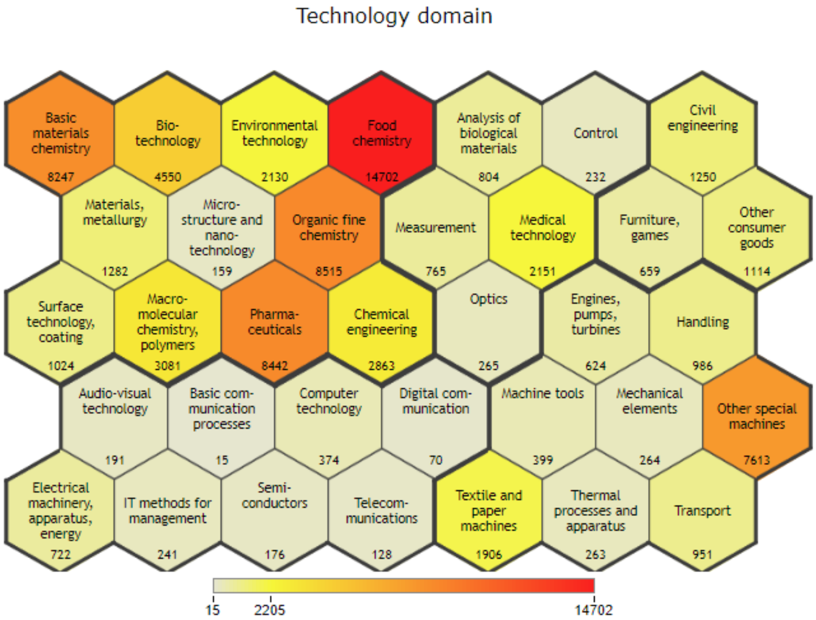

Figure 5. Technology domains and respective number of patent families for seaweed portfolio

By assessing the top 10 players and top 10 technology domains for **granted patent families,** it is noticed that Organic fine chemistry and Basic Material Chemistry are the technology domains where most patents fit in. There is a great predominance of Organic fine chemistry domains in the portfolio of granted patents families (Fig. 6). Inclusively KAO (producer of chemistry products and cosmetics) and Shiseido (cosmetic company), the two major players in the granted seaweed portfolio, have a propensity to protect inventions in the area of Organic fine chemistry. However, food chemistry is the domain with more patent families with a total of 6996 patents. As already explained, this is derived by the fact that a patent has more than one technology domain and the assignees that do not belong to the top assignees group operate mostly in the food chemistry area.

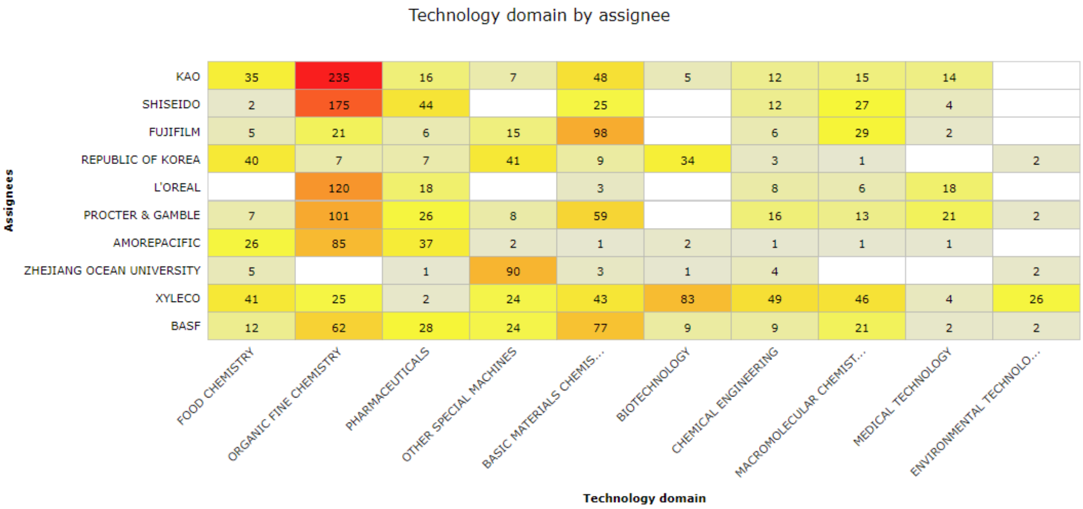

Figure 6. Top 10 assignees and respective technology domains for granted patents from the seaweed portfolio

To analyse future trends, the **pending patent families** were analysed. Even though top assignees vary in relation to granted patent families, the major technology domains are the same. As a Result, Changsha Xiehaoji Biology Engineering (feed additive sector), Zhejiang Ocean University and BASF (chemistry sector – sustainable chemistry) are the leading assignees with more pending patents, showing their investment in Research & Development (Fig. 7).

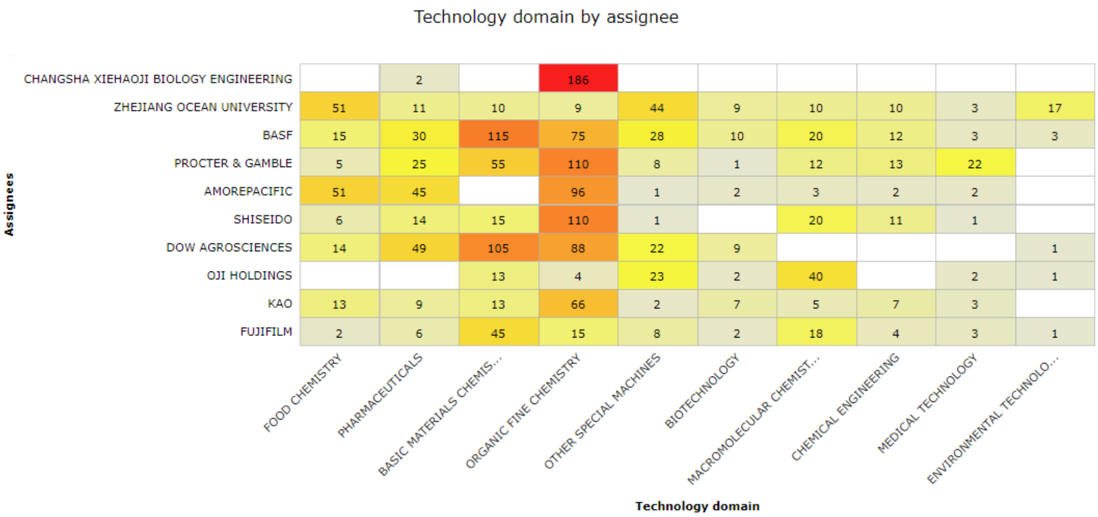

Figure 7. Top 10 assignees and respective technology domains for pending patents from the seaweed portfolio

The most used concepts in pending patent families are listed in the Fig. 8. The concepts enable the identification of the most relevant technical terms that represent the future trends of the macroalgae market. For obvious reasons, seaweed, seaweed extract, algae and marine algae are concepts used in several patent families. However, it is important to note that carrageenan, seaweed powder, kelp (brown algae) and seaweed polysaccharide are recurrent concepts in pending patents and, in fact, those concepts are many times linked to the food chemistry (a fundamental domain in the present and in the future of seaweed market). It is pertinent to note that the concept "Spirulina seaweed" is wrongly, presented. Spirulina is not even a "Seaweed OR Macroalgae OR Marine algae", since it is a microalgae (Villarruel-López, Ascencio, and Nuño 2017). This confusion about the conjugation of these two terms could be explained by the fact that the two concepts were misused since seaweed is used as synonymous of algae, which is incorrect.

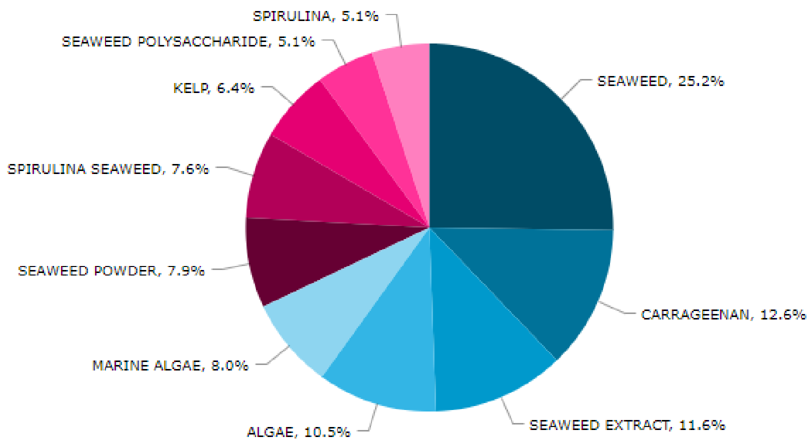

Figure 8. Top 10 concepts for the macroalgae pending patents

A. Green Macroalgae

Green macroalga, as *Ulva lactuca* or *Monostroma sp.* (Gomez-Zavaglia et al. 2019), is the class of seaweed with the highest number of patents, accounting for a total of 11225 patent families. In line with the results showed beyond, 2017 was also the year with most applications (1567 patent families). In the Fig. 9 we observe that Kyoei Kagaku Kogyo (Japanese company), the University of California and DSM (company operating in Nutrition, Health & Sustainable Living) are the three top players, being the University of

California the assignee with most granted patent families (51) and the MIT (Massachusetts Institute of Technology) the player with more pending patents (37).

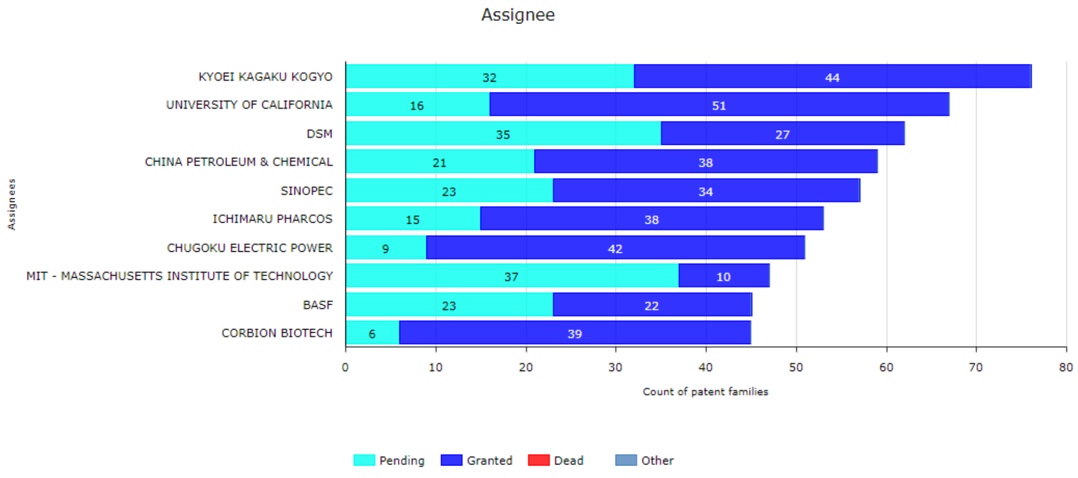

Figure 9. Top 10 key players and respective patent families with legal status for green algae portfolio

The top 10 players detain, only, 4 % of the 11225 patent inventions. Although China continues to be in the lead of the market with 5253 patents, the concepts are diversified, being Biotechnology and Environmental Technology the main technology domains. From the concepts represented in the Fig. 10 it is possible highlight: Culture (8.60 %), Microorganism (8.58 %) and Active Ingredient (8.36 %).

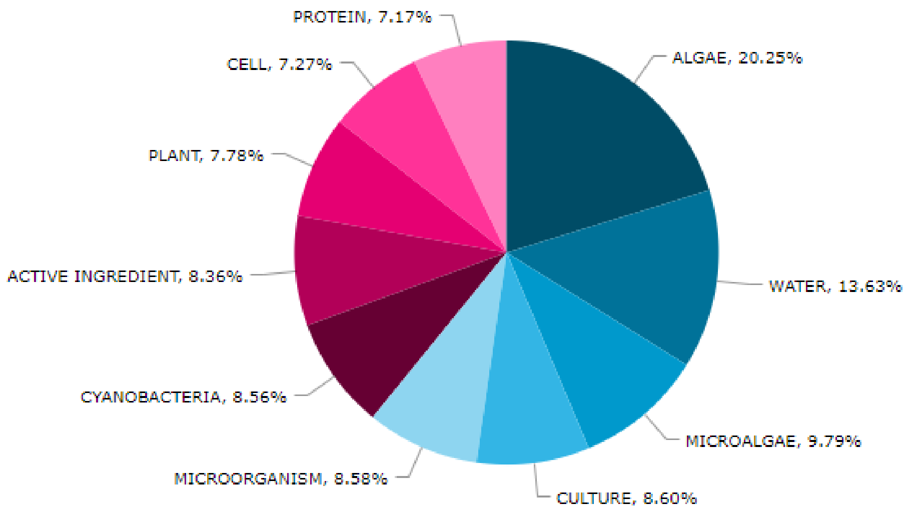

Figure 10. Top 10 concepts reported in green algae portfolio

B. Brown Macroalgae

With a total of 7686 patent families, **brown macroalgae**, as *Undaria sp.* or *Laminaria sp*. (Gomez-Zavaglia et al. 2019), are the second major group of macroalgae with most patent inventions. The year with most applications, over the last twenty years, was 2017 with 931 patent families. The Fig. 11 represents the top 10 assignees and the legal status of their patents. Shiseido, L'Oreal (French cosmetic company) and Kyoei Kagaku Kogyo are the top three key players with a total of 203, 126 and 78 patent families, respectively. Shiseido is the company with more pending and granted patents related to brown algae. Nevertheless, the top 10 players only detain 10 % of all patent inventions and the market with more patent families related is the Chinese, with 2816 patents. The technology domains with more patent families are Organic fine chemistry and Food chemistry

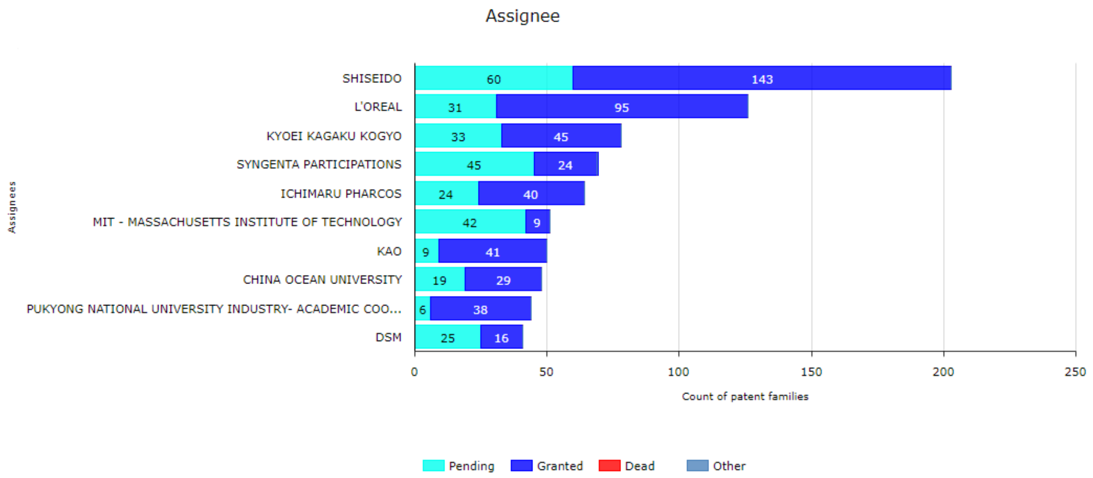

Figure 11. Top 10 key players and respective patent families with legal status for brown algae portfolio

Evaluating the top 10 concepts (Fig. 12) related with brown algae are, we can empathize: Cosmetic (15.01 %); Active Ingredient (14.18 %) and Alginate (10.06 %). The concepts are mostly related with Organic fine chemistry and Food Chemistry and, in fact, the major concepts, "cosmetic" and "active ingredient", are related with beauty care/cosmetic sector which was also observed for the major key players.

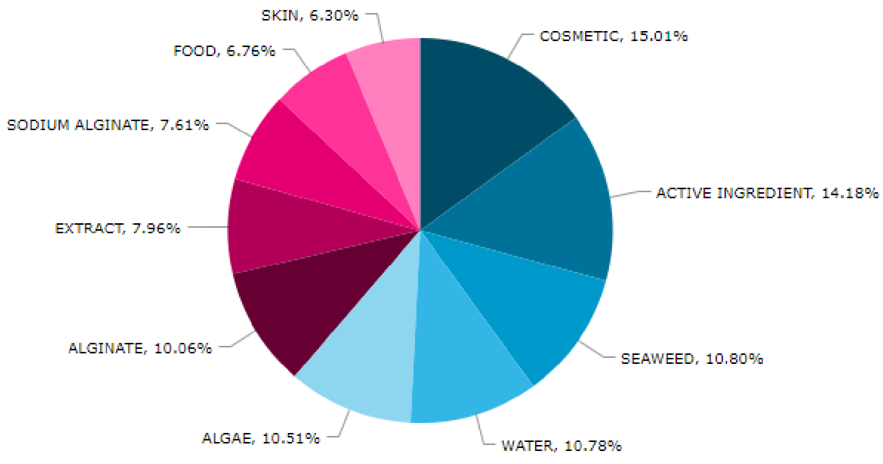

Figure 12. Top 10 concepts reported in brown algae portfolio

C. Red Macroalgae

For last, **red algae**, like *Palmaria palmata* (Gomez-Zavaglia et al. 2019), is the phylum of seaweed with the smallest portfolio. With 7461 patent families and just 9 % detained by the top 10 players, the red macroalgae are also an important key in the Chinese market with 3211 patent families. Unlike brown and green algae, 2016 was the year with most patent applications for red algae, with a total of 803 patents. Kyoei Kagaku Kogyo, Konica Minolta (Japanese company producer of professional equipment) and Shiseido are the major top players (Fig. 13). KAO is the company with most granted patents related to red algae and Kyoei Kagaku Kogyo is the assignee with more pending patents.

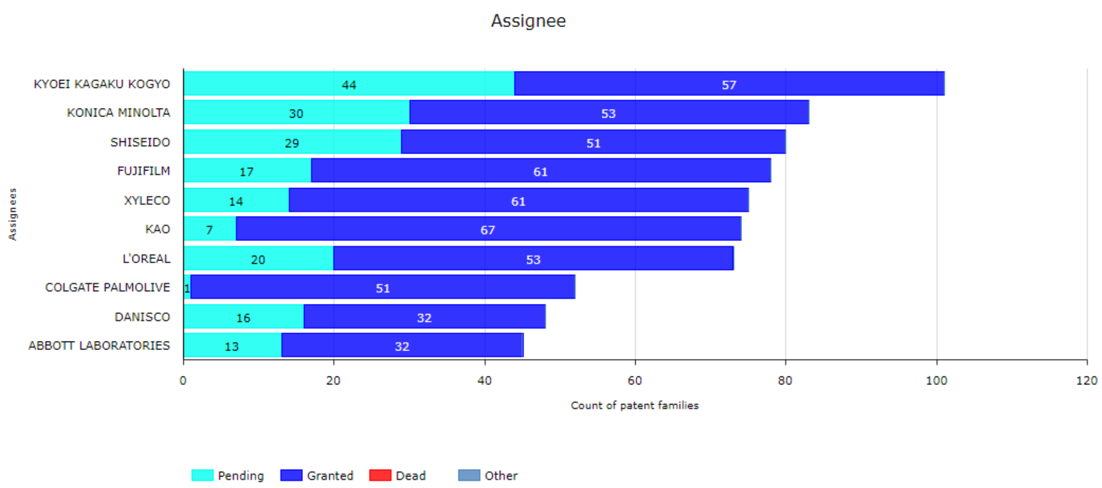

Figure 13. Top 10 key players and respective patent families with legal status for red algae portfolio

Pharmaceuticals followed by Organic fine chemistry are the most important technology domains. Active ingredient (14.43 %); Cosmetic (12.97 %) and Carrageenan (11.36 %) (Fig. 14) are important concepts.

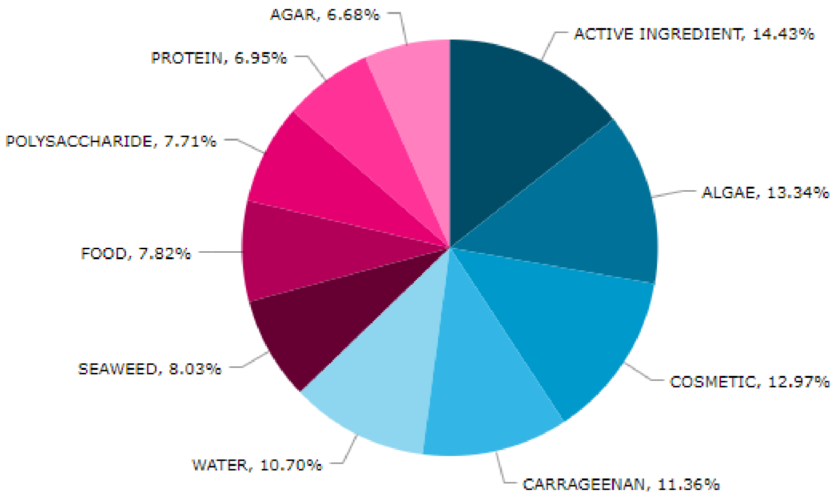

Figure 14. Top 10 concepts reported in red algae portfolio

3.1.2.1.1 Case Study: Portugal

For the case study of **Portugal,** The Institute Polytechnic of Leiria (IPL) and the University of Minho (UM) are the two Portuguese assignees with more alive patent families, with 2 pending and 1 granted, and 3 granted, respectively (Fig. 15). In Portugal 58 % of all patent inventions for seaweed portfolio are owned by the top 10 players showed below. It is important clarify that CNRS (Fig. 15) is not a Portuguese assignee despite the software consider it by default.

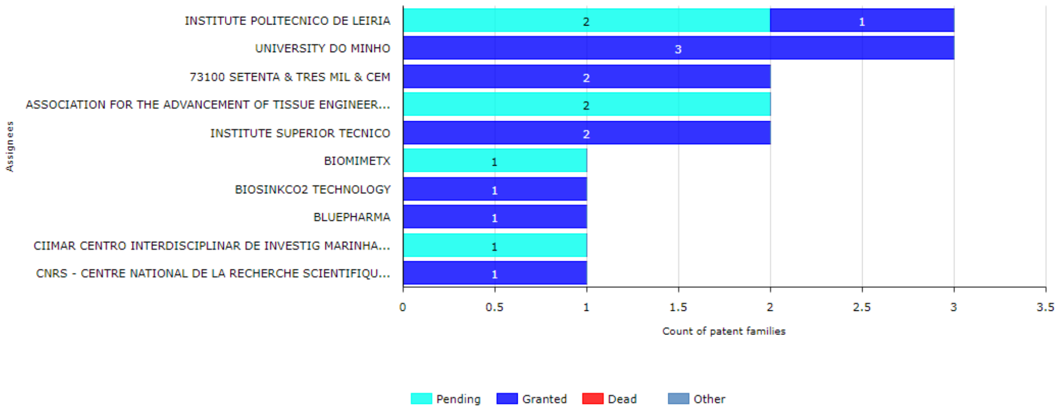

Figure 15. Top 10 key players and respective patent families with legal status for the Portuguese seaweed portfolio

For a better knowledge about which areas/domains are being explored in the Portuguese market, a brief and summary information about the patents detained by the top player with more pending patents is presented in the Table 11. The patent EP3560988 A1 is related with the formulation and manufacturing process of an edible food conditioning film, EP3491932 A1 is linked with the formulation of an inventive feed for omnivorous fish and WO2011/058398 A1 is related with an product that enhances food quality and security.

Table 11. Patent family number and respective brief abstract from the 3 patents detained by IPL

	Patent family number	**Brief Abstract**
IPL	EP3560988 A1	**Edible food** conditioning film and to its active, biodegradable manufacturing process composed of bioactive ingredients of seaweed for application in food matrices with high fat content susceptible to oxidation.
	EP3491932 A1	**Feed** for omnivorous fish (aquaculture and aquarium-keeping feeding fish) which allows their growth and healthy development with a diet comprising innovative nutrient ingredients with a low production cost
	WO2011/058398 A1	**Biotechnological product**, to a type of ice supplemented with edible algae and/or derivatives thereof. Preferably, algae and their derivatives present high antioxidant and bioactive capacities. Thus, when applied to fresh food, the ice allows increasing the preservation time delaying its deterioration.

2013 was the year with most applications per patent families, with a total of 4 patent families. Between 2001 and 2004, inclusively, no submission in the seaweed portfolio with Portuguese assignees was performed.

The technology domain with most associated patents families is the sector of **pharmaceuticals**. Basic materials chemistry, biotechnology and food chemistry follow pharmaceuticals has the most relevant sectors for Portuguese assignees. It becomes pertinent to know which concepts are associated with the dominant technology domain. Thus, the three key technology domains use as key concepts: culture medium, culture, and *Pseudomonas aeruginosa* (Fig. 16). Culture medium is the concept integrated in a bigger count of patent families, more precisely 12.

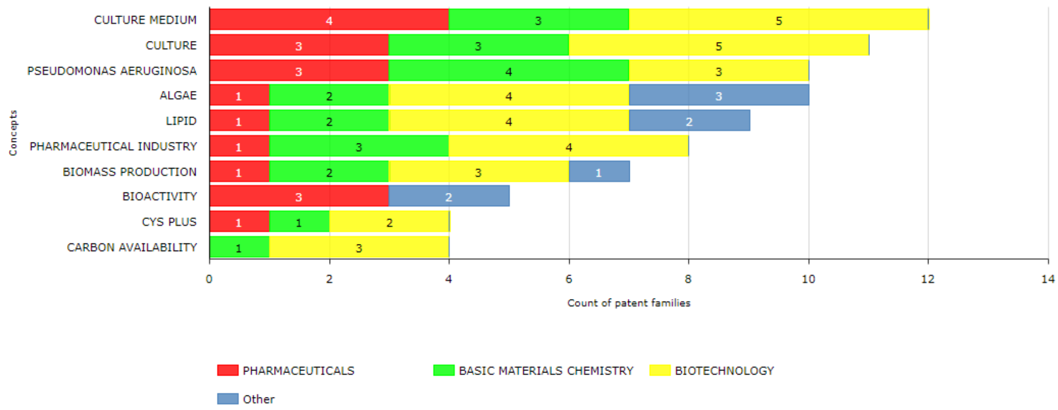

Figure 16. Major concepts used by the major technology domains from the Portuguese seaweed portfolio

3.1.2.2 Microalgae

Analysing the data obtained for the microalgae portfolio, it was observed that in the last twenty years, 2017 was the year with most applications, counting with 1733 alive patent families. However, as occurred with macroalgae portfolio, there is a decreasing trend for the following years, with only 1125 patent families in 2019. In fact, 2017 represented a turning point, since from 2000 to 2017 there was always a continued growth in the number of patent families and after 2017 there was a downward trend. As in the case of seaweed portfolio, China is also the country with the most patent families (6337 patents) in the microalgae portfolio, holding 21.10 % of the market. The USA follows China with a market share of 8.9 % (2682 patent families).

Examining the top 10 assignees (Fig. 17) (detaining 7 % of all patent families), ENN Science & Technology Development, a Chinese company, is the main player with 216 patent families. Of the 216 patent families, 26 are pending and 190 are granted. In this case, ENN Science & Technology Development, which operates in the field of energy, is the company with the largest number of guaranteed patents. MIT and Broad Institute, USA institutions, are the organizations with most pending patents (65 patent families) which is an indicative of the strong support of R&D activities in the case of these institutions.

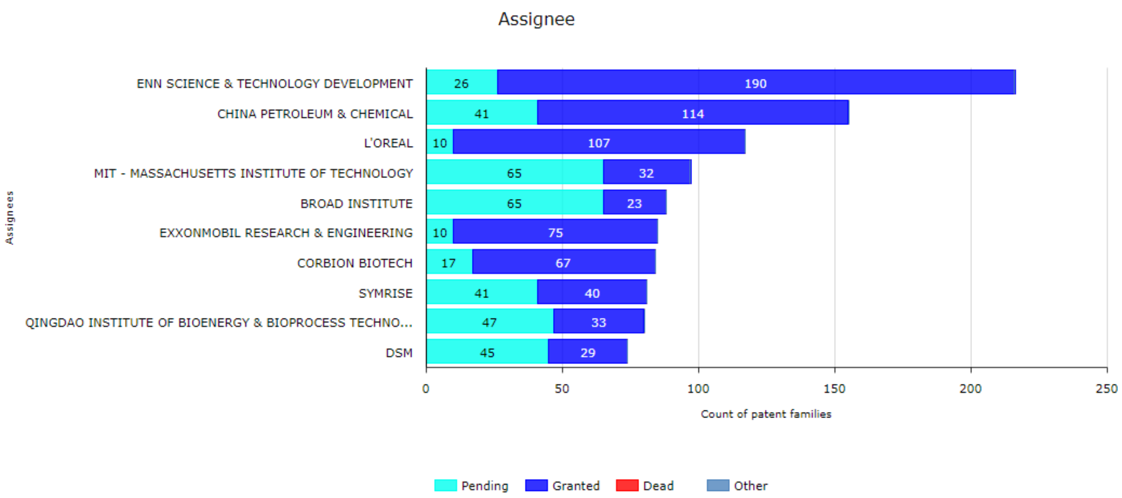

Figure 17. Top 10 key players and respective patent families with legal status for microalgae portfolio

The technology domains were also analysed and are presented in the Fig. 18. Biotechnology is, unquestionably, the major technology domain with 6278 patent families. Food chemistry and Basic materials chemistry are also relevant technology domains with 2138 and 2118 patent families, respectively. Thus, Chemistry group, that includes all the technology domains mentioned, is the major group of the portfolio.

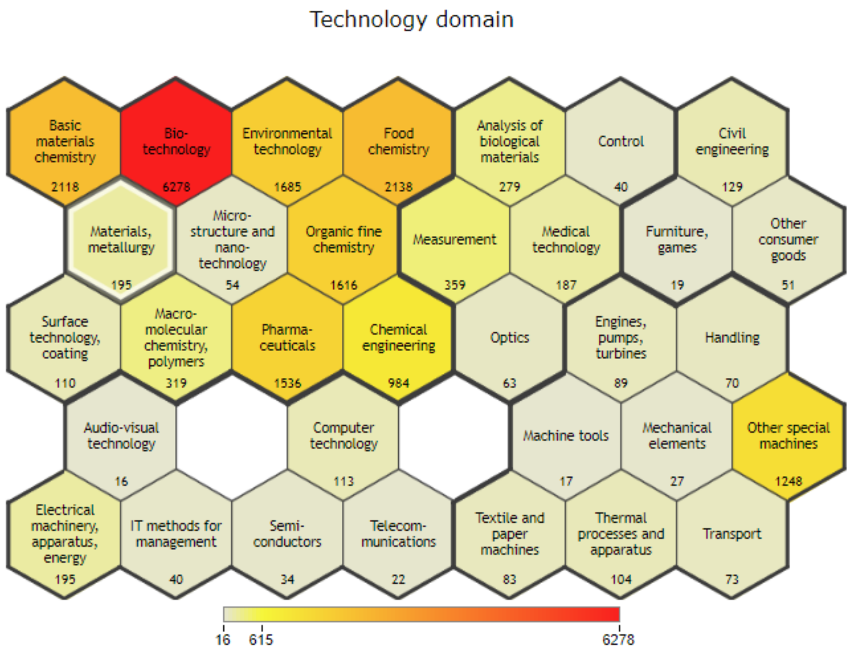

Figure 18. Technology domains and respective number of patent families for microalgae portfolio

Through the analysis of the top 10 players and top 10 technology domains for **granted patent families** (Fig. 19), it is observed that Biotechnology is the technology domain with most granted patent families associated. In fact, Biotechnology detain 3893 granted patent families. It turns pertinent to focus the companies ENN Science & Technology Development with 156 patents related with Biotechnology and L'Oreal with 100 patents related with Organic Fine Chemistry.

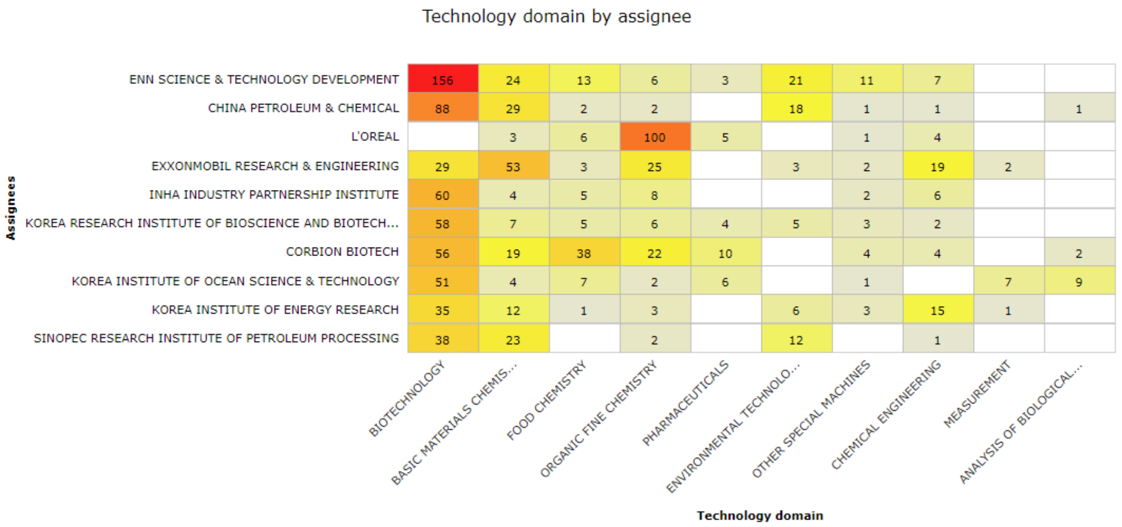

Figure 19. Top 10 assignees and respective technology domains for granted patents from the microalgae portfolio

Pending patent families were also analysed to assess the future trends of the microalgae market. As noticed for the granted patent families, also for the case of pending patent families it appears that biotechnology is the main technology domain. Nevertheless, the organizations that have a higher number of pending patents are different from those that have the higher number of granted patents (Fig. 20). In this case, MIT and Broad Institute stands out, which is an indication of the greater commitment of these organizations in the promotion of R&D in the field of Biotechnology. Also, Exxonmobil Research & Engineering (Energy company), Symrise (Flavor, nutrition and scent & care company) and Celgene (Pharmaceutical company) are considered top assignees for Basic Materials Chemistry, Organic Fine Chemistry and Pharmaceuticals domains, respectively.

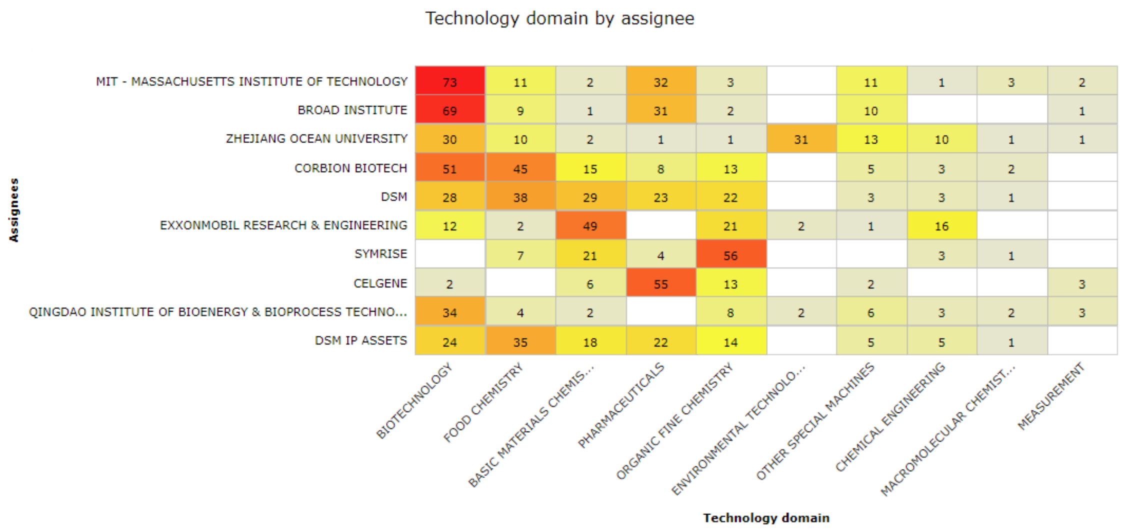

Figure 20. Top 10 assignees and respective technology domains for pending patents from the microalgae portfolio

The major concepts that define the microalgae portfolio are presented in the Fig. 21. As already explained for the seaweed portfolio, the concepts enable the identification of the technical terms/keywords that will characterize the microalgae market trends. As it happened for the macroalgae portfolio, the direct concepts associated with the portfolio are commonly used. Nevertheless, Chlorella (9.81 %) and Photobioreactor (7.39 %) are in the top 10 concepts. The term *Chlorella* can be informative of the potential use of the microalgae for different applications and exploration in different technology domains and the term photobioreactor can be indicative of the big exploration of Biotechnology, for the microalgae culture using a light source. It also important highlight terms related with microalgae cultivation, as "Microalgae Culture" or "Microalgae Growth", showing the trend and exploration/investment in matters related with microalgae production.

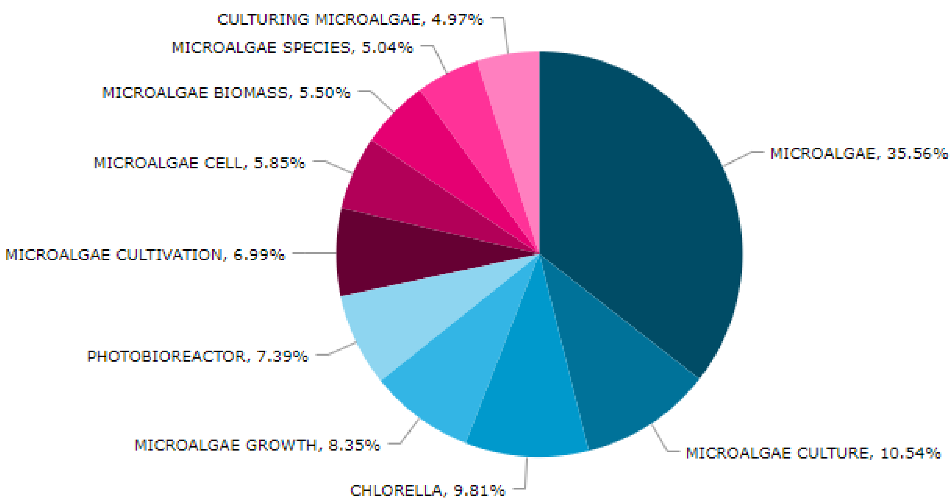

Figure 21. Top 10 concepts for microalgae pending patents

3.1.2.2.1 Case Study: Portugal

73 % of the Portuguese microalgae portfolio is maintained by the top 10 players. IPL and the University of Oporto (UP) are the two top assignees with a total of 2 patents each (Fig. 22). IPL has one pending patent and one granted patent and UP has two pending patents.

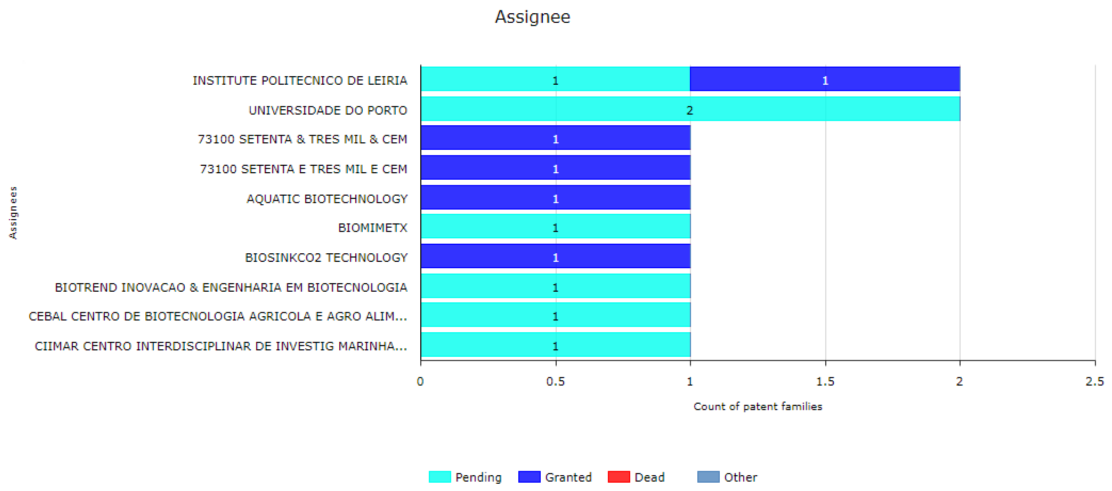

Figure 22. Top 10 key players and respective patent families with legal status for Portuguese microalgae portfolio

In order to understand a little bit better the areas that are being investigated in the Portuguese market, it is presented in the table 12 a succinct information about the pending patents detained by UP (that demonstrated the biggest growth rate in the last years). It is important clarify that the patent WO2018/173011 A1 is not directly related with microalgae.

Table 12. Patent family number and respective brief abstract from the 2 patents detained by UP

	Patent Family Number	**Brief Abstract**
University of Oporto	WO2019/171293 A1	**Method** for obtaining proteins or a rich-protein extract from algae, extracts and uses therefore, as a food ingredient and/or as feed for farmed fish and shellfish species
	WO2018/173011 A1	Heterogeneous catalysts, preparation process and application thereof in fatty acid alkyl esters production process

2009 and 2017 were the years with most applications per patent families, with a total of 3 patent families. Between 2000 and 2006 and in the years 2008, 2011, 2015 and 2020 (until now, June of 2020) there was no submissions by Portuguese institutions.

The technology domains with most related patent families are: Biotechnology and Food Chemistry, with a total of 5 patents for each domain. Following these domains, Environmental Technology is also a key domain with a total of 4 patents. In the Fig. 23 is presented the main 10 concepts identified in the different patent families which are associated with the main 10 technology domains. Thus, Biotechnology uses preferentially the concepts "Culture" and "Pharmaceutical Industry" (in 5 patent families). Food chemistry uses mostly the concept "Algae" (in 4 patent families) and Environmental Technology has a uniformly use of the concepts.

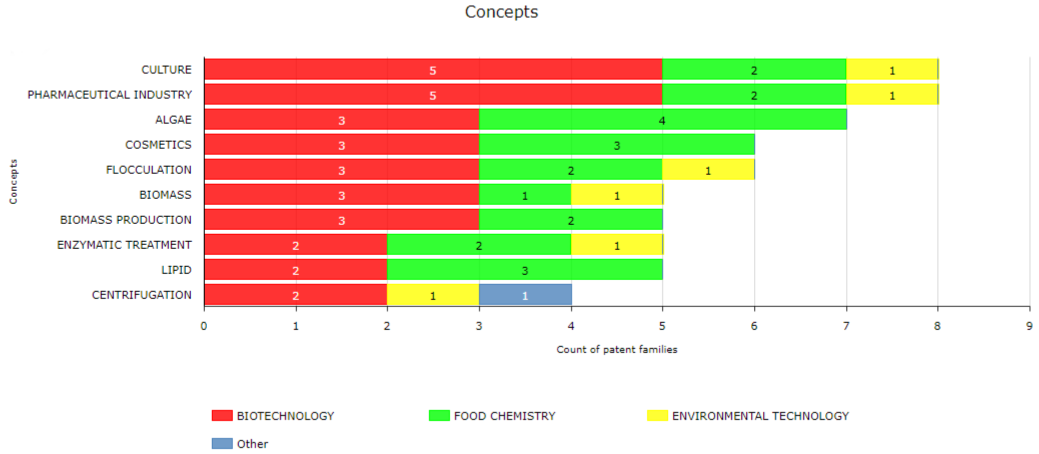

Figure 23. Major concepts used by the major technology domains from the Portuguese microalgae portfolio

3.2 Bibliometric Analysis

3.2.1 Descriptive analysis using WoS database

3.2.1.1 Macroalgae

The search process identified a total of 3510 documents between 2000 and 2020. 731 (20.83 %) documents had as subject area "Food Science Technology" or "Nutrition Dietetics". From those 731 documents, 713 (97.54 %) were articles or reviews.

Analysing the number of publications per year (Fig. 24), it is evident that academic interest in the subject has increased rapidly in the last few years, especially since 2015, being 2019 the year in which the greatest number of publications occurred (104) (up to now). This trend suggests that, also for the academic research, seaweeds are being increasingly searched and studied. The progressively interest in macroalgae can be attributed, on one hand, to the need of scientific evidences to corroborate existing ideas and claims or, on the other hand, to discover, characterize and explore new seaweed species, compounds, biological activities, properties, and among others. In all cases, scientific information is crucial, as regulatory agencies require very high levels of standardized efficacy, for functional or nutraceutical foods, to be demonstrated clinically before health claims can be made to support marketing (Hafting et al. 2015).

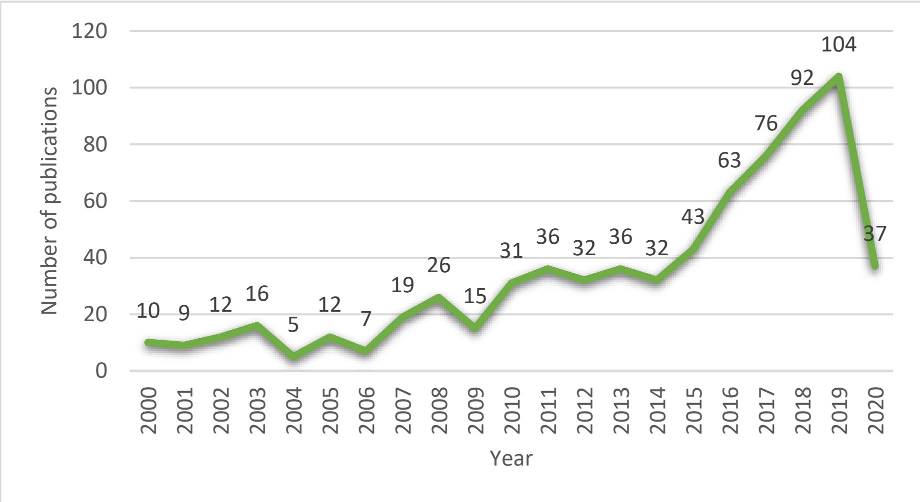

Figure 24. Number of publications per year for macroalgae research

The top 10 countries with most publications are presented in the Fig. 25. South Korea leads the ranking with 118 (16.55 %) articles/reviews. Spain and Japan follows with 107 (15.01 %) and 91 (12.76 %) documents, respectively. Despite the small geographical dimension of Portugal (compared with the other countries), that could be a disadvantage, Portugal ranks eighth as the country with the most publications. This position can be due to the fact that Portugal presents one of the largest exploration marine areas in Europe, with an extremely rich and varied seaweed flora (Vieira et al. 2018). In reality, it is important to notice that the Iberian Peninsula (Spain and Portugal) is located in the warm temperate, Mediterranean-Atlantic region and that Iberian coast has unique conditions for the development of macroalgal flora (Cardoso et al. 2014). This location and privileged conditions may be related to the fact that in these Iberian countries there are a significant number of research institutes and researchers with a high productivity in this area, leading these countries to occupy the top 10 of the countries with the most published documents.

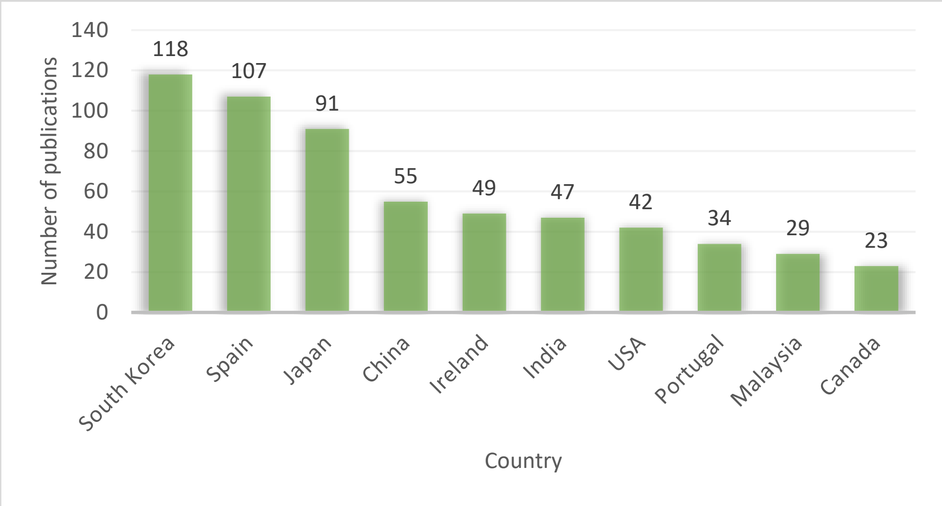

Figure 25. Top 10 countries with most published documents between 2000-2020 for seaweed

The top 10 sources with most documents associated are presented in the Fig. 26. As we can observe Food Chemistry is, by far, the journal with the most articles/reviews published, with a total of 77, corresponding to 30 % of all documents of the sample. The Journal of Agricultural and Food Chemistry follows with a total of 35 documents (14 %). The journals with highest impact factor, that provides a functional approximation of the mean citation rate per citable item [9], according to Journal Citation Reports of WoS, are: Food Hydrocolloids and Food Chemistry with an impact factor, of 7.1 and 6.3, respectively.

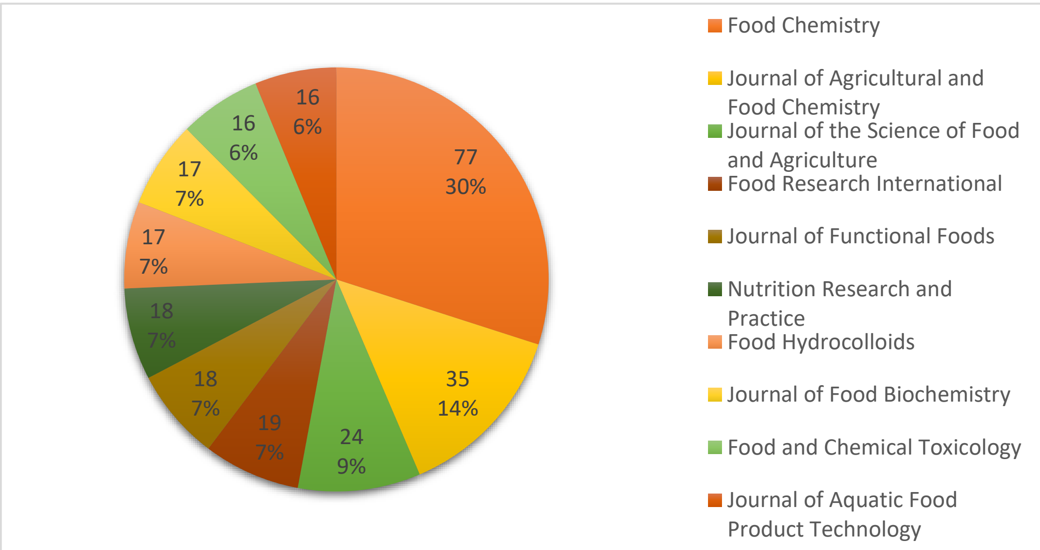

Figure 26. Top 10 journals sources by number of publications and respective percentage, for seaweed case study

[9] For example, a Journal Impact Factor of 1.0 means that, on average, the articles published one or two years ago have been cited one time (Source: http://jcr.help.clarivate.com/Content/glossary.htm)

The top 10 articles that received the most citations are listed in Table 13. With 368 citations, the most cited publication was the article entitled "Potential antioxidant capacity of sulfated polysaccharides from the edible marine brown seaweed F*ucus vesiculosus*" written by Ruperez,P; Ahrazem,O and Leal,JÁ published in the Journal of Agricultural and Food Chemistry. The study called "FTIR-ATR spectroscopy as a tool for polysaccharide identification in edible brown and red seaweeds" written by Gomez-Ordonez, Eva and Ruperez, Pilar and published in Food Hydrocolloids is the top-cited document according to average citations per year (23.80).

Table 13. The most cited articles in seaweed research

NO	ARTICLE	YEAR	AUTHOR(S)	JOURNAL NAME	TOTAL CITATION	AVERAGE CITATION PER YEAR
1	Potential antioxidant capacity of sulfated polysaccharides from the edible marine brown seaweed *Fucus vesiculosus*	2002	Ruperez, P; Ahrazem, O; Leal, JÁ	Journal of Agricultural and Food Chemistry	368	19.37
2	Evaluation of antioxidant property of extract and fractions obtained from a red alga, *Polysiphonia urceolata*	2006	Duan, XJ; Zhang, WW; Li, XM; et al.	Food Chemistry	328	21.87
3	Mineral content of edible marine seaweeds	2002	Ruperez, P	Food Chemistry	317	16.68
4	Ciguatera: recent advances but the risk remains	2000	Lehane, L; Lewis, RJ	International Journal of Food Microbiology	279	13.29
5	In the search of new functional food ingredients from algae	2008	Plaza, Merichel; Cifuentes, Alejandro; Ibanez, Elena	Trends in Food Science & Technology	266	20.46
6	Antioxidant activity of fresh and processed edible seaweeds	2001	Jimenez-Escrig, A; Jimenez-Jimenez, I; Pulido, R; et al.	Journal of the Science of Food and Agriculture	254	12.70
7	Antioxidant activity of dulse (*Palmaria palmata*) extract evaluated in vitro	2005	Yuan, YV; Bone, DE; Yuan, YV	Food Chemistry	247	15.44
8	FTIR-ATR spectroscopy as a tool for polysaccharide identification in edible brown and red seaweeds	2011	Gomez-Ordonez, Eva; Ruperez, Pilar	Food Hydrocolloids	238	23.80
9	Dietary fibre from edible seaweeds: chemical structure, physicochemical properties and effects on cholesterol metabolism	2000	Jimenez-Escrig, A; Sanchez-Muniz, FJ	Nutrition Research	235	11.19
10	Seaweeds: A sustainable functional food for complementary and alternative therapy	2012	Mohamed, Suhaila; Hashim, Siti Nadia; Rahman, Hafeedza Abdul	Trends in Food Science & Technology	213	23.67

3.2.1.2 Microalgae

The search process for microalgae identified a total of 3332 documents between 2000 and 2020. The subject areas "Food Science Technology" or "Nutrition Dietetics" had 376 (11.28 %) documents. From those 376 documents, 367 (97.61 %) were articles or reviews. When comparing with the data obtained in the macroalgae analysis, it is possible to affirm that microalgae have less publications in the select subject areas (11.28 % for microalgae against 20.83% for macroalgae), although the number of results obtained is close for both analysis (3510 documents for macroalgae and 3332 documents for microalgae).

Considering the number of publications per year (Fig. 27), there has been a steady increase, especially since 2017, with 2019 being the year with the highest number of publications (83). This is indicative of the growing interest that this area has been receiving from the academic community. The growth since 2017 until 2019, in the case of microalgae was more pronounced compared to macroalgae for the same time range. Although we are in the middle of the year (2020) and in the middle of a world pandemic, microalgae have, already, 42 publications in 2020. This growth trend in academic research in the last three years (2017, 2018 and 2019) is coincident with the growing demand for sustainable food supply. Microalgae is considered a *green* alternative to the production of several products such as carotenoids, proteins, fatty acids, dietary supplements, and nutraceuticals. In terms of revenues, food & beverages is a major application segment of global microalgae-based products market, being a highly lucrative segment (Transparency Market Research 2019). However, until reaching the market, similarly to seaweed, microalgae studies and academic researches must be done to find evidences/proves that fulfil strict food safety regulations (Rizwan et al. 2018).

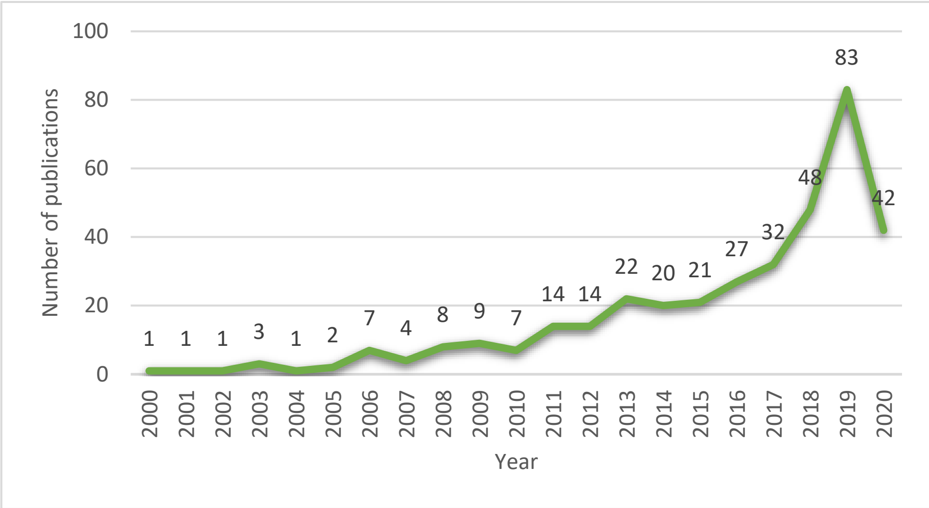

Figure 27. Number of publications per year for macroalgae research

The top 10 countries with most publications are shown in the Fig. 28. Spain leads the ranking, unquestionably, with 47 (12.81 %) documents. Brazil, China, USA, France, and Germany have on average 32 publications, India and Portugal have 24 and Italy 21 publications.

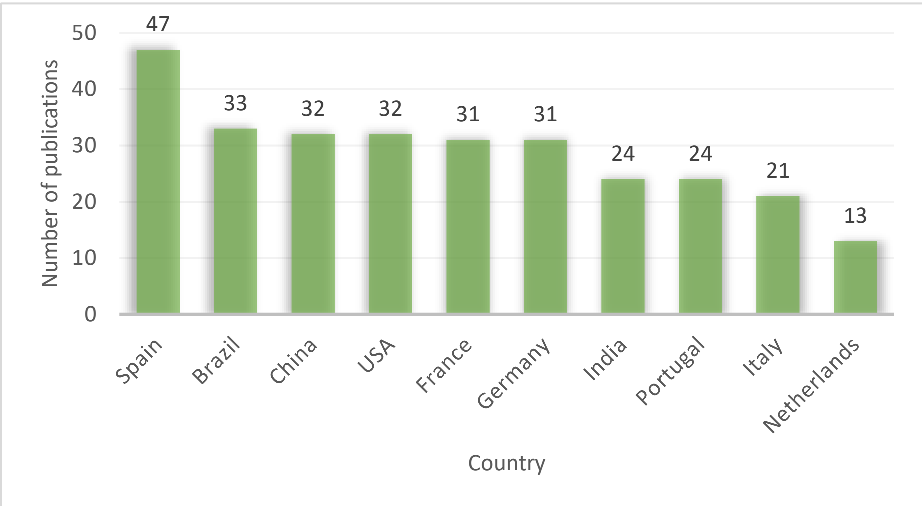

Figure 28. Top 10 countries with most published documents between 2000-2020 for microalgae

The top 10 journal sources with most published documents are presented in the Fig. 29. Food Chemistry leads, again, the top 10 with 27 (18 %) publications and the Journal of Agricultural and Food Chemistry follow with 21 (14 %) publications.

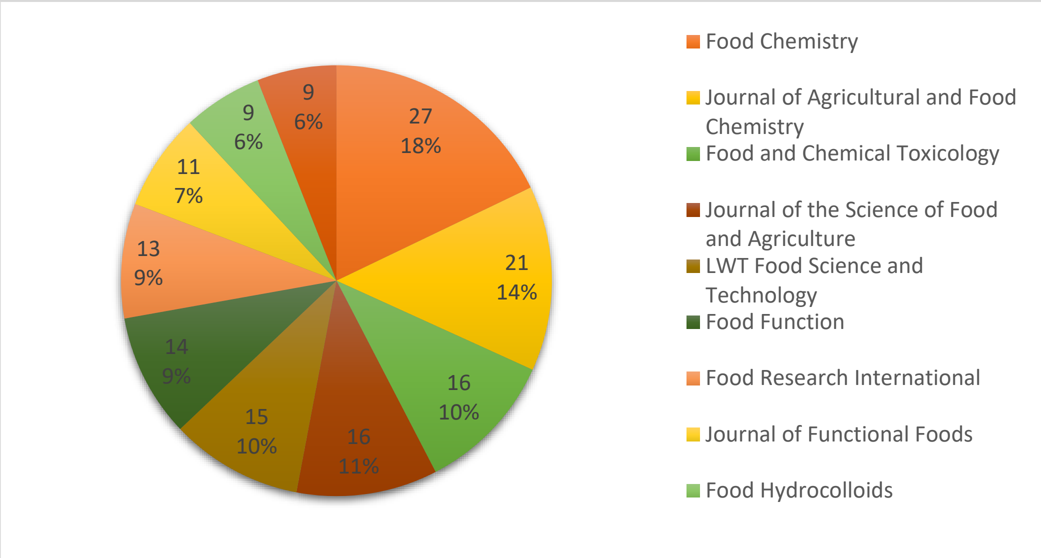

Figure 29. Top 10 journals sources by number of publications and respective percentage, for microalgae case study

The top 10 documents that received the most citations are listed in table 14. The most cited article is entitled "Commercial applications of microalgae" with 1981 citations written by Spolaore, Pauline; Joannis-Cassan, Claire; Duran, Elie and Isambert, Arsène, and published in the Journal of Bioscience and Bioengineering.

3.2.2 Co-authorship and Co-occurrence analysis using VOSviewer

3.2.2.1 Macroalgae

In order to understand the future research trends, we opt to analyse the last 3 years of publications in more detail, since it may provide us a more accurate vision of what are currently the hot topics of research. Therefore, the data extracted from WoS for the bibliographic analysis was selectively filtered taking in consideration the publication period (2017-2020), type of document (articles and reviews), and language. Thus, between 2017 and 2020, 317 (23.46 %) documents were related to the subject areas "Food Science Technology" and/or "Nutrition Dietetics". From those, 309 (97.48 %) were articles or reviews and from those 309 articles/reviews, 306 (99.03 %) were written in English.

Table 14. The most cited articles/reviews in microalgae research

NO	ARTICLE	YEAR	AUTHOR(S)	JOURNAL NAME	TOTAL CITATION	AVERAGE CITATION PER YEAR
1	Commercial applications of microalgae	2006	Spolaore, P; Joannis-Cassan, C; Duran, E; et al.	Journal of Bioscience and Bioengineering	1981	132.07
2	Sub- and supercritical fluid extraction of functional ingredients from different natural sources: Plants, food-by-products, algae and microalgae - A review	2006	Herrero, M; Cifuentes, A; Ibanez, E	Food Chemistry	632	42.13
3	Lipids and lipid metabolism in eukaryotic algae	2006	Guschina, IA; Harwood, JL	Progress in Lipid Research	533	35.53
4	Microorganisms and microalgae as sources of pigments for food use: a scientific oddity or an industrial reality?	2005	Duffose, L; Galaup, P; Yaron, A; et al.	Trends in Food Science & Technology	304	19.00
5	Innovative Natural Functional Ingredients from Microalgae	2009	Plaza, Merichel; Herrero, Miguel; Cifuentes, Alejandro; et al.	Journal of Agricultural and Food Chemistry	203	16.92
6	Isolation and characterisation of a novel angiotensin I-converting enzyme (ACE) inhibitory peptide from the algae protein waste	2009	Sheih, I-Chuan; Fang, Tony J.; Wu, Tung-Kung	Food Chemistry	158	13.17
7	Microalgae for "Healthy" Foods-Possibilities and Challenges	2010	Chacon-Lee, T.; Gonzalez-Marino, G.E.	Comprehensive Reviews in Food Science and Food Safety	148	13.45
8	Microbial production of food grade pigments	2006	Dufosse, Laurent	Food Technology and Biotechnology	135	9.00
9	Safety of Novel Protein Sources (Insects, Microalgae, Seaweed, Duckweed, and Rapeseed) and Legislative Aspects for Their Application in Food and Feed Production	2013	van der Spiegel, M.; Noordam, M.Y.; van der Fels-Klerx, H.J.	Comprehensive Reviews in Food Science and Food Safety	134	16.75
10	Functional properties of carotenoids originating from algae	2013	Christaki, Efterpi; Bonos, Eleftherios; Glannenas, Ilias; et al.	Journal of the Science of Food and Agriculture	118	14.75

The **co-authorship** was analysed using the different units: authors, organizations, and countries. Note that the links show the interactions between items which can be authors, organizations, or countries. Firstly, the co-authorship between researchers (**authors**) was analysed. With a minimum of two documents per author, the software found 158 authors, which are grouped in 41 clusters. However, some of the 158 authors (items) were not connected to each other. So, the largest set of connected items (a total of 16 items) was selected (Fig. 30). Examining the figure, we can identify three clusters (red, blue, and green cluster) and verify that the network has mostly Portuguese authors interacting. Carlos Cardoso and Claudia Afonso are the authors with higher document weight (five documents), indicating their importance in relation to the others. Consequently, these authors have more co-authorship links with other researches, a total of 11 links. The cluster 1 (red one) has more items, a total of eight items; cluster 2 (green one) has six items and cluster 3 (blue one) has two items. For macroalgae co-authorship analysis using authors, Portuguese authors leads the presented network and have the largest set of items connected.

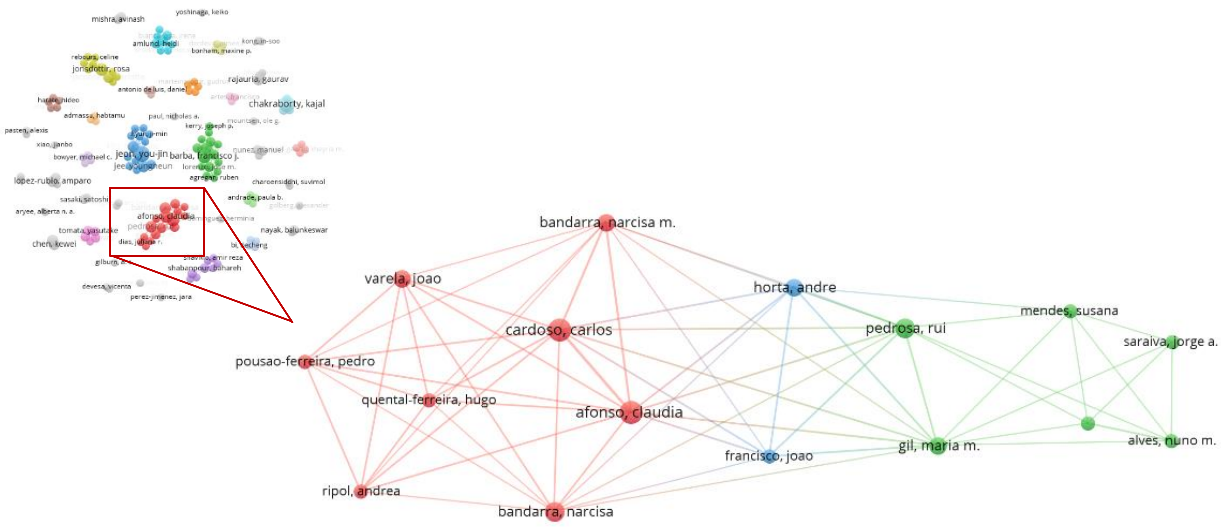

Figure 30. Network visualization map of co-authorship analysis using authors for seaweed case study

Analysing the co-authorship between **organizations**, and considering a minimum of three documents per organization, 45 items were identified. Due to the absence of connections between all the 45 them, only the largest set of connect items (a total of 25 items) was analysed in more detail (Fig. 31). In this case, it is possible to identify five clusters (green, yellow, red, blue, and purple). Clusters 1 and 2 (red one and green one, respectively) have six items; cluster 3 (blue one) has five items and clusters 4 and 5 (yellow one and purple one, respectively) have four items. CSIC (*Consejo Superior de Investigaciones Científicas*), a Spanish state agency, is the organization with more weight (13 documents) and has a total of 4 links. University of Oporto is also a relevant item with a total of 12 associated documents. The cluster 5 is represented by Portuguese institutions: IPMA (*Instituto Português do Mar e da Atmosfera*), University of Algarve, University of Coimbra, and University of Oporto.

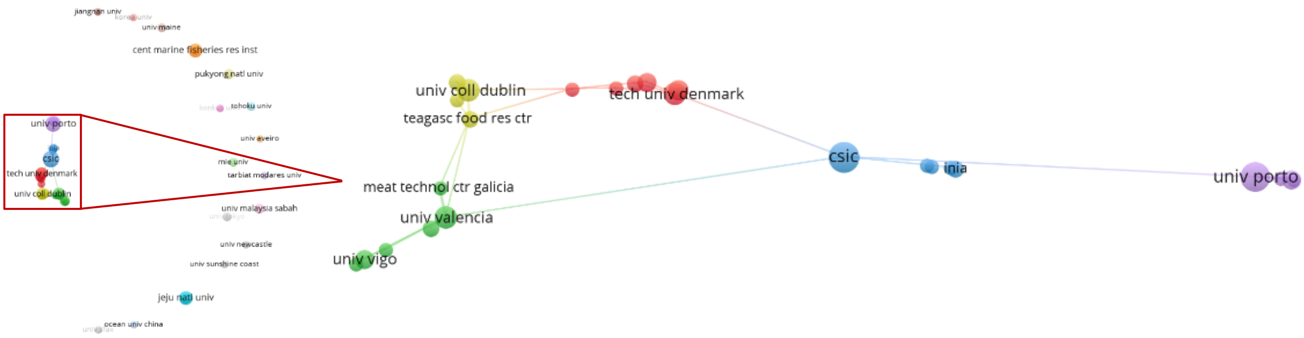

Figure 31. Network visualization map of co-authorship analysis between organizations for seaweed case study

Examining now the co-authorship between **countries**, with a minimum of three documents per country, 33 items were displayed in the map (Fig. 32). We can recognize seven clusters (red, green, dark blue, yellow, purple, light blue, and orange). The cluster 1 (red one) has twelve items; cluster 2 (green one) has six items; cluster 3 (dark blue one) has five items; clusters 4 and 5 (yellow and purple one, respectively) have three items and clusters 6 and 7 (light blue and orange one, respectively) have two items. The cluster 1 is the biggest one and has a large number of Asian countries (items) with significant weight: South Korea has 43 documents and 5 links; Japan has 34 documents and 4 links; China (item between Japan and New Zeeland) has 33 documents and 11 links. Like South Korea, Spain (cluster 5) has also 43 documents (same weight) and has a total of 15 links. Spain and USA are the two countries with most links (a total of 15) – demonstrating the great cooperation of those countries with the others and vice-versa. Observing the figure, we can also highlight Portugal (green cluster) that has a detachable item with 23 documents. Portugal has 4 links with Canada, Ireland, Italy, and Spain and a total link strength of 5 (two co-authored publications with Spain and one co-authored publication with Canada, Ireland, and Italy).

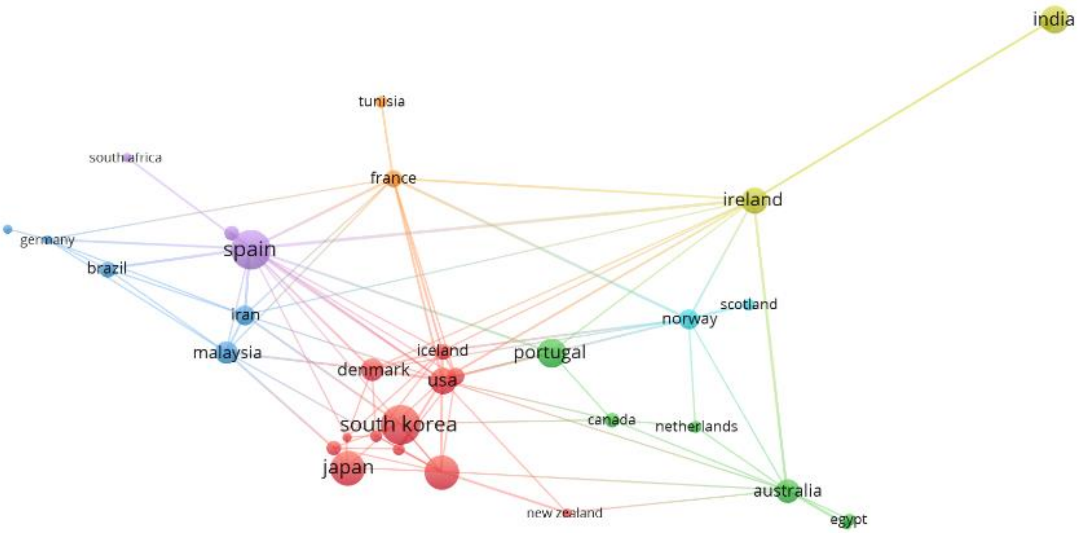

Figure 32. Network visualization map of co-authorship analysis between countries for seaweed case study

The **co-occurrence** analysis was performed using the **author-keywords** and 53 items were exhibited. The **network map** is presented in the Fig. 33. Analysing the figure, it is possible distinguish eight clusters (red, green, dark blue, yellow, purple, light blue, orange and brown). The cluster 1 (red colour) has a total of twelve items; cluster 2 (green colour) has a total of eleven items; clusters 3 and 4 (dark blue and yellow, respectively) has seven items; cluster 5 (purple colour) has five items; clusters 6 and 7 (light blue and orange, respectively) has 4 items and, for last, cluster 8 (brown colour) has a total of three items.

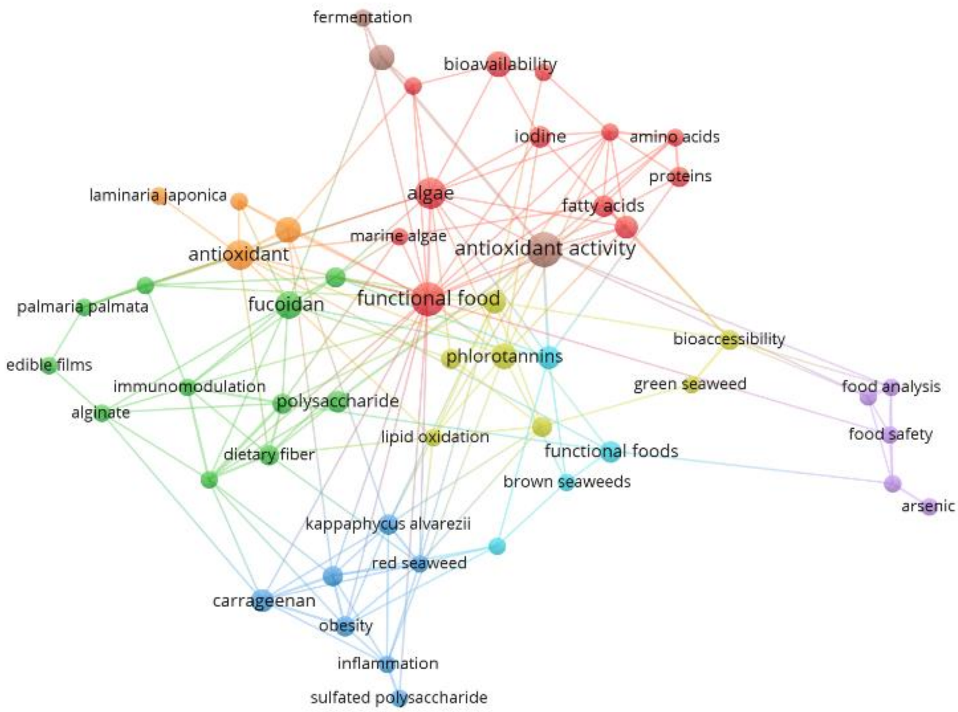

Figure 33. Network visualization map of co-occurrence analysis using author keywords for seaweed case study

In the tables 15 and 16 the terms obtained by the previous network were enumerated by their weight (link weight or occurrence weight [10], respectively). The term "**antioxidant activity**", is the term with **major occurrence weight**, 16 occurrences and 11 links. "Functional food" and "antioxidant", also noteworthy terms, have 14 occurrences and 22 links and 11 occurrences and 11 links, respectively. Furthermore, "**functional food**" is the term with **major links** (22) and with the **major total link strength** (24). The occurrence of those terms is coherent with the potential of seaweed as an antioxidant source and as a resource of the multiple compounds capable of improving human health. The keywords are very varied in each cluster and can be correlated for many reasons. However, it is possible to understand that:

- Cluster 2 (green) is more related with the potential of seaweeds, as *Saccharina latissima*, as a source of polysaccharides/dietary fiber with prebiotic ability to improve the microbiota;
- Cluster 5 (purple) is more correlated with food quality and safety;
- Cluster 6 (light blue) may be related with the extraction of brown seaweed compounds to control adipogenesis;
- The potential of seaweed (red, green, or brown seaweed) as an antioxidant source is widely study;
- Seaweeds are extensively study to prove their label as "functional food", for several reasons.

[10] Indicates the number of documents in which a keyword occurs.

Table 15. Identification of the author-keywords, for seaweed case study, per Cluster in descending order for link weight (from the term with more links to the term with less ones)

CLUSTER 1 (RED)	CLUSTER 2 (GREEN)	CLUSTER 3 (DARK BLUE)	CLUSTER 4 (YELLOW)	CLUSTER 5 (PURPLE)	CLUSTER 6 (LIGHT BLUE)	CLUSTER 7 (ORANGE)	CLUSTER 8 (BROWN)
LINK WEIGHT							
Functional Food (22)	Gut Microbiota (10)	Red seaweed (11)	Antioxidants (13)	Food analysis (5)	Extraction (7)	Antioxidant (11)	Antioxidant activity (11)
Algae (13)	Fucoidan (9)	*Kappaphycus alvarezii* (9)	Phlorotannins (10)	Food composition (5)	Adipogenesis (5)	Anti-inflammatory (6)	Brown seaweed (4)
Minerals (10)	Prebiotics (9)	Metabolic syndrome (9)	Lipid oxidation (8)	Heavy metals (5)	Functional foods (5)	Phlorotannin (4)	Fermentation (2)
Fucoxanthin (8)	Bioactivity (8)	Carrageenan (8)	Bioaccessibility (6)	Food safety (4)	Brown seaweeds (4)	*Laminaria japonica* (1)	
Fatty Acids (6)	Dietary Fiber (8)	Obesity (8)	Volatile compounds (6)	Arsenic (1)			
Iodine (6)	Immunomodulation (8)	Inflammation (7)	*Fucus vesiculosus* (4)				
Amino acids (5)	Alginate (7)	Sulfated polysaccharide (2)	Green seaweed (2)				
Bioactive Compounds (5)	*Saccharina latissima* (6)						
Marine algae (5)	*Palmaria palmata* (4)						
Bioavailability (4)	Polysaccharide (4)						
Proteins (4)	Edible Films (2)						
Kombu (3)							

Table 16. Identification of the author-keywords, for seaweed case study, per Cluster in descending order for occurrence weight (from the term with more occurrences to the term with less ones)

CLUSTER 1 (RED)	CLUSTER 2 (GREEN)	CLUSTER 3 (DARK BLUE)	CLUSTER 4 (YELLOW)	CLUSTER 5 (PURPLE)	CLUSTER 6 (LIGHT BLUE)	CLUSTER 7 (ORANGE)	CLUSTER 8 (BROWN)
OCCURENCE WEIGHT							
Functional Food (14)	Fucoidan (9)	Carrageenan (7)	Phlorotannins (8)	Same Occurrence (4)	Extraction (7)	Antioxidant (11)	Antioxidant activity (16)
Algae (12)	Polysaccharide (6)	*Kappaphycus alvarezii* (5)	Antioxidants (7)		Functional foods (6)	Anti-inflammatory (8)	Brown seaweed (8)
Bioavailability (8)	Bioactivity (5)	Metabolic syndrome (5)	Bioaccessibility (5)		Adipogenesis (4)	*Laminaria japonica* (4)	Fermentation (4)
Fucoxanthin (7)	Dietary Fiber (5)	Obesity (5)	*Fucus vesiculosus* (5)		Brown seaweeds (4)	Phlorotannin (4)	
Fatty Acids (6)	Prebiotics (5)	Inflammation (4)	Volatile compounds (5)				
Iodine (6)	Alginate (4)	Red seaweed (4)	Green seaweed (4)				
Proteins (5)	Fucoidan (4)	Sulfated polysaccharide (4)	Lipid oxidation (4)				
Amino acids (4)	Gut Microbiota (4)						
Bioactive Compounds (4)	Immunomodulation (4)						
Kombu (4)	*Palmaria palmata* (4)						
Marine algae (4)	*Saccharina latissima* (4)						
Minerals (4)							

The **overlay map**, where items have scores, is presented in the Fig. 34. The score is related with the average publication year, ranging the score from blue (lowest average publication year) to green to yellow (biggest average publication year). Between the middle of 2017 to beginning of 2018 the most used terms were: “fucoidan”; “dietary fiber”; “bioavailability”; “obesity”; “inflammation”; “sulfated polysaccharide”; “green seaweed”; “*Kappaphycus alvarezzi*”. From the beginning of 2018 to the middle of 2018 the terms more employed were, principally: “antioxidant activity”; “functional food”; “phlorotannins”; “fermentation”; “lipid oxidation”; “red seaweed”; “fatty acids”; “food safety”; “edible films”; “alginate” and “immunomodulation”. The terms “*Palmaria palmata*”, “*Laminaria japonica*” and “carrageenan” are being more used since the end of 2018/beginning of 2019, demonstrating the academic interest in edible seaweeds, namely, red, and brown seaweeds and in the phycocolloid industry. Although not visible in the figure 34, the yellow item between “*Palmaria palmata*” and “antioxidant” is the term “*Saccharina latissima*”, which also corroborates with the previous statements.

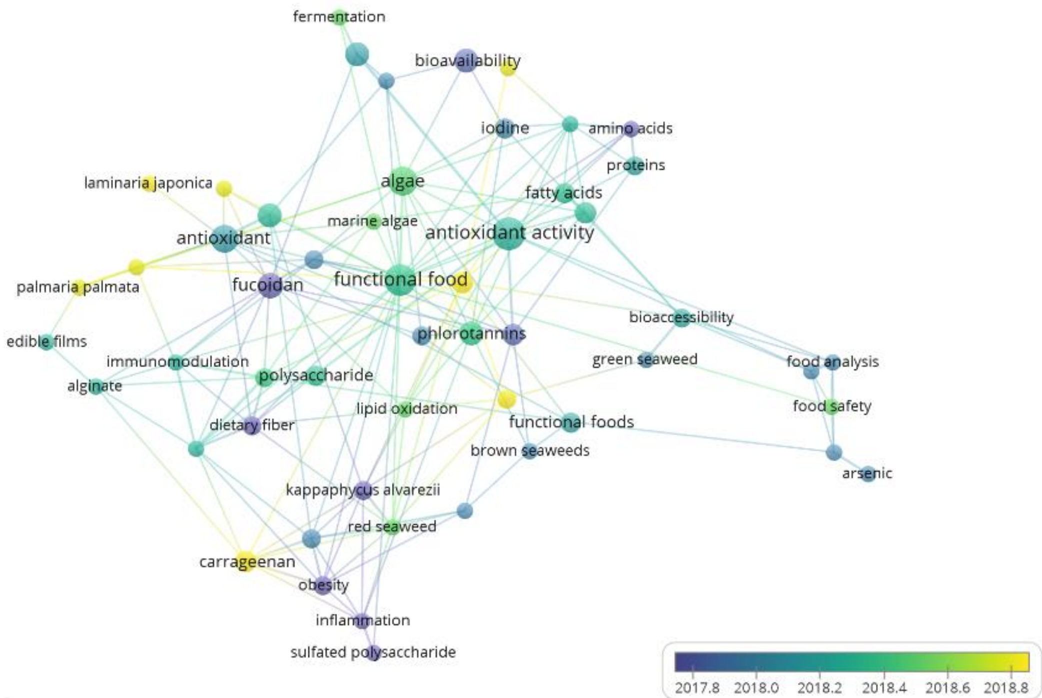

Figure 34. Overlay visualization map of co-occurrence analysis using author keywords for seaweed case study

3.2.2.2 Microalgae

Also, for the microalgae research, the data extracted from WoS was selectively filtered. Between 2017 and 2020, 211 (14.36 %) documents were related to the select subject areas, “Food Science Technology”/ “Nutrition Dietetics”. From those 211 documents, 205 (97.16 %) were articles or reviews and from those, 202 (98.54 %) are in English.

Co-authorship between **authors** was firstly analysed. With the minimum of two documents per author, VOSviewer found 109 authors. From the 109 authors, some of them were not connected to each other. Thus, only the largest set of connect items (10 items) was selected (Fig. 35). Observing the figure, it is possible identify 2 clusters (green and red clusters). Both clusters (cluster 1 is the red one and cluster 2 is the green one) have 5 items. The authors Imogen Foubert and Lore Gheysen have the highest number of documents (9 documents), being the authors (items) with more weight, and with a total of 9 links each one. Those authors are associated with the Belgium University KU Leuven. In fact, Belgian authors lead the presented co-authorship researchers map.

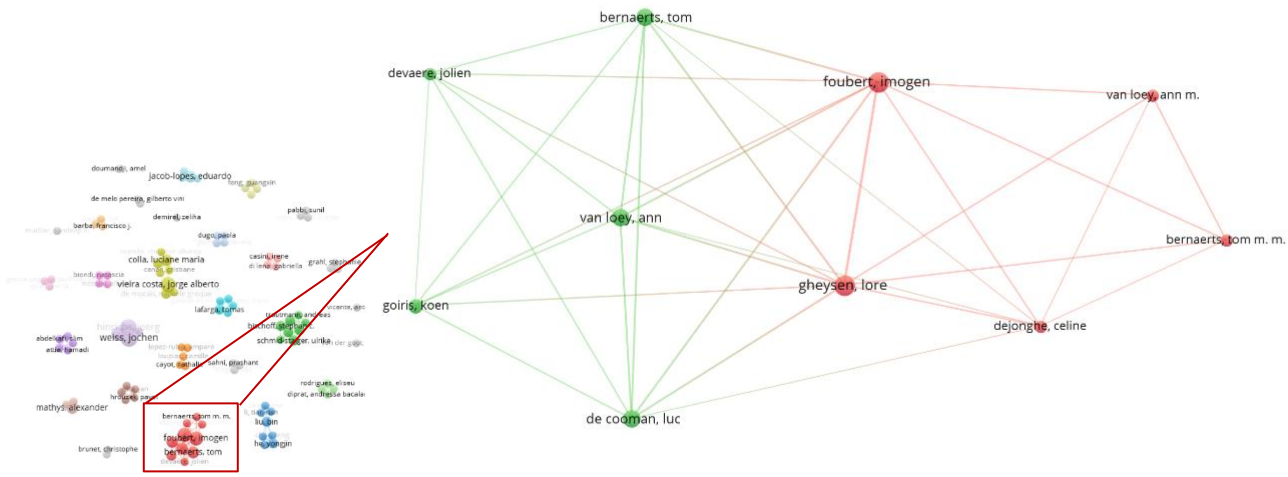

Figure 35. Network visualization map of co-authorship analysis using authors for microalgae case study

Analysing the co-authorship between **organizations,** and considering a minimum of 3 documents per organization, 21 items were found. From those, the largest set of connected items was only 3. Just one cluster, with three items, was obtained. The items were three German academic institutions: Karlsruhe Institute of Technology;

Hohenheim University and Stuttgart University. There is no interaction between different clusters for microalgae case study, only interaction between items. In this case, the major set is detained by German organizations. For microalgae case study it is clear that organizations try to make an autonomous/independent academic research, not having a notable teamwork between institutions.

Examining the co-authorship between **countries**, and considering a minimum of three documents per country, 27 items were created. The largest set of connected items (23 items) were used to create the map (Fig. 36). Observing the figure, we can find five clusters (red, green, blue, yellow, and purple). Clusters 1, 2, 3, 4 (red, green, blue, and yellow, respectively) have five items, and cluster 5 (purple) has three items. We can highlight Germany (from cluster 1) with 22 documents and 4 links; China (from cluster 2) with 22 documents and 5 links; Spain (cluster 3) with 26 documents and 8 links; Brazil (cluster 5) with the biggest weight (27 documents) and 7 links. Even though Brazil seem to be the country with most documents, France (blue item below Brazil) and Spain are the countries with more links (a total of eight), having those two countries a bigger interaction between other countries. Portugal (purple cluster/cluster 5) has 10 documents, and 3 links with a total link strength of 6 (three co-authored publications with Brazil, two with Italy and one with South Korea).

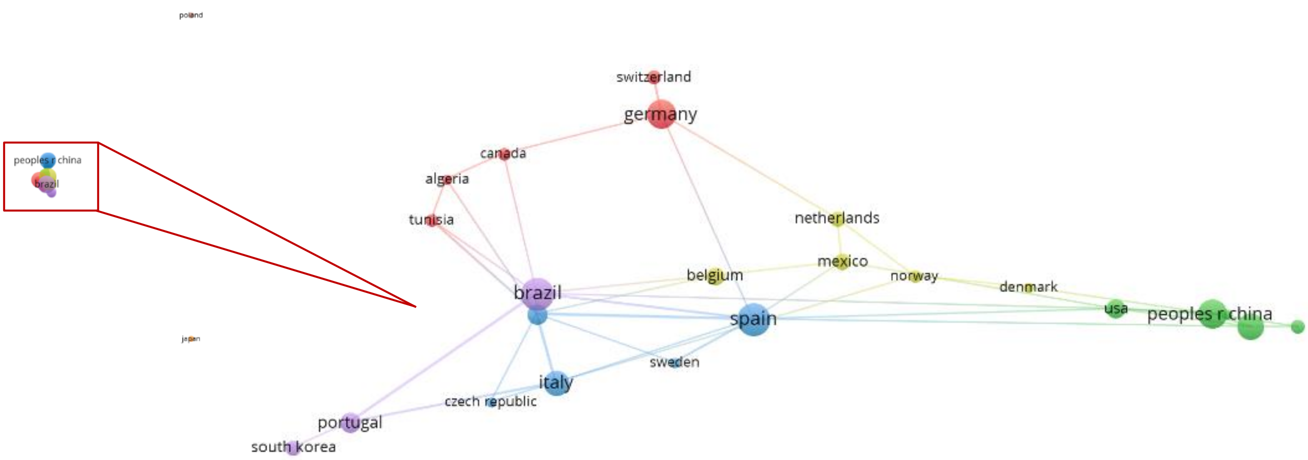

Figure 36. Network visualization map of co-authorship analysis between countries for microalgae case study

The **co-occurrence** analysis using the **author-keywords** for microalgae was also performed and 32 items were displayed. The **network map** is presented in the Fig. 37. Studying the map, we can identify 5 clusters (red, green, blue, yellow, and purple). The cluster 1 (red) has nine items; cluster 2 (green) has seven items; clusters 3 and 4 (blue and yellow, respectively) have six items and cluster 5 (purple one) has four items.

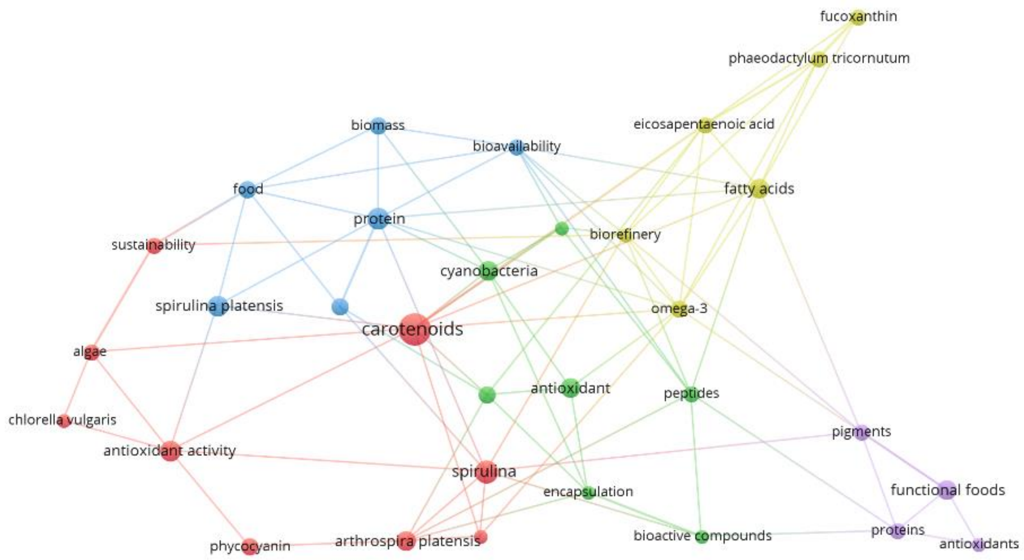

Figure 37. Network visualization map of co-occurrence analysis using author keywords for microalgae case study

In the tables 17 and 18 the terms obtained by the network were enumerated by their weight (link weight or occurrence weight, respectively). The term "**carotenoids**" is the term with **more occurrence weight**, 19 occurrences, **major total link strength** (11) and has a total of 10 links. As already explored in the section 1.4.2, microalgae are an incredible source of carotenoids, being largely used as bioactive ingredient in food and used as natural colouring agent. For those reasons, the fact that "carotenoids" be the main term in the map can be related with the increasing interest in the study of the potentialities of microalgae pigments. The terms "**carotenoids**" and "**omega-3**" are the ones with **most links** (10 in total). Analysing the information demonstrated in the tables the tables 17 and 18, it is possible highlight the following facts:

- Cluster 4 (yellow) is related with the utilization of microalgae, in particular their fatty acids, as biomass source for the production of biofuels, energy, and others (Biorefinery);

- Spirulina and Chlorella are the microalgae more widely study;
- Terms related with the antioxidant capacity of microalgae are also explored, as “antioxidant” or “antioxidant activity”;
- Pigments are usually present in different clusters, as “carotenoids”, “phycocyanin” or “pigments”.

For last, the **overlay map** is shown in the Fig. 38. Beginning of 2018 was marked by the terms: “antioxidants”, “fatty acids”, “peptides” and “pigments”. Between the end of the first few months of 2018 and the middle of 2018, the most applied terms were: “antioxidant”, “antioxidant activity”, “biorefinery”, “*Chlorella vulgaris*”, “fucoxanthin”, “functional foods”, “*Phaeodactylum tricornutum*”, “protein” and “spirulina”. Approximately at the end of 2018, the terms “*Arthrospira plantesis*”, “bioavailability”, “biomass”, “carotenoids”, “cyanobacteria”, “omega-3”, “spirulina platensis” and “sustainability” were more used. The terms: “bioactive compounds”, “chlorella” (the yellow item between “spirulina” and “food”), “eicosapentaenoic acid”, “encapsulation”, “food”, “functional food” (the yellow item between “encapsulation” and “carotenoids”) and “proteins” are occurring with a higher frequency in 2019.

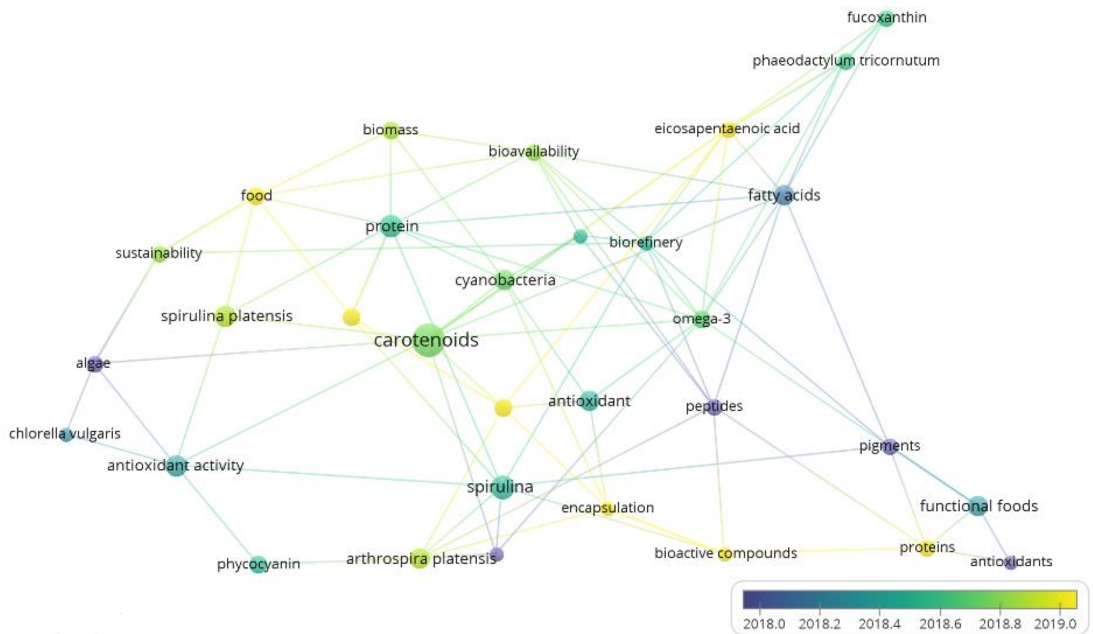

Figure 38. Overlay visualization map of co-occurrence analysis using author keywords for microalgae case study

Table 17. Identification of the author-keywords, for microalgae case study, per Cluster in descending order for link weight (from the term with more links to the term with less ones)

Cluster 1 (Red)	**Cluster 2 (Green)**	**Cluster 3 (Dark Blue)**	**Cluster 4 (Yellow)**	**Cluster 5 (Purple)**
		LINK WEIGHT		
Carotenoids (10)	Peptides (7)	Protein (9)	Omega-3 (10)	Pigments (5)
Spirulina (8)	Cyanobacteria (6)	Bioavailability (8)	Biorefinery (9)	Proteins (5)
Antioxidant activity (6)	Functional food (6)	Food (6)	Fatty acids (9)	Functional foods (4)
Arthrospira platensis (6)	Encapsulation (5)	Biomass (4)	Eicosapentaenoic acid (7)	Antioxidants (2)
Algae (4)	Phycobiliproteins (5)	Chlorella (4)	*Phaeodactylum tricornutum* (5)	
Lipids (4)	Antioxidant (4)	*Spirulina platensis* (4)	Fucoxanthin (3)	
Sustainability (3)	Bioactive compounds (4)			
Chlorella vulgaris (2)				
Phycocyanin (2)				

Table 18. Identification of the author-keywords, for microalgae case study, per Cluster in descending order for occurrence weight (from the term with more occurrences to the term with less ones)

CLUSTER 1 (RED)	CLUSTER 2 (GREEN)	CLUSTER 3 (DARK BLUE)	CLUSTER 4 (YELLOW)	CLUSTER 5 (PURPLE)
OCCURENCE WEIGHT				
Carotenoids (19)	Antioxidant (7)	Protein (9)	Fatty acids (7)	Functional foods (7)
Spirulina (10)	Cyanobacteria (7)	*Spirulina platensis* (8)	Omega-3 (6)	Pigments (5)
Antioxidant activity (8)	Functional food (6)	Biomass (6)	Eicosapentaenoic acid (5)	Proteins (5)
Arthrospira platensis (7)	Peptides (5)	Chlorella (6)	Fucoxanthin (5)	Antioxidants (4)
Phycocyanin (6)	Bioactive compounds (4)	Food (6)	*Phaeodactylum tricornutum* (5)	
Algae (5)	Encapsulation (4)	Bioavailability (5)	Biorefinery (4)	
Sustainability (5)	Phycobiliproteins (4)			
Chlorella vulgaris (4)				
Lipids (4)				

4. Conclusions

The current study had as objective use Technology Surveillance and Technology Forecasting approaches to evaluate the present and the future of algae market and research trends. For the analysis of the macro- and microalgae general market trends a patent analysis was performed, using the software Orbit Intelligence®, and to study the academic literature/research trends in food sector we carry out a bibliometric analysis, through the platform Web of Science and the software VOSviewer.

The seaweed portfolio has a total of 49582 alive patent families (56 % granted and 44 % pending patents) and their top used IPC codes gives us the information of the interest of applications in beauty and skin care. This information is also corroborated by the top two assignees for granted patent families: KAO and Shiseido (cosmetic companies). 2017 was the year with highest number of applications and China is the country that detain the biggest slice of the portfolio (34 %). Despite the huge potential and exploration of seaweed in cosmetics, Food Chemistry is the major technology domain with 14702 patent families, followed by Organic Fine Chemistry with 8515 patent families. “Carrageenan”, “seaweed powder” and “kelp” are recurrent concepts in pending patents and are usually related with Food Chemistry. Green algae are the class of seaweed with highest number of patents (11225) and Biotechnology and Environmental Technology are the main technology domains. Brown algae, with 7686 patent families, are very related with Organic Fine Chemistry due to the huge interest of those macroalgae in cosmetic/skin care – L’Oreal and Shiseido are the top key players and “cosmetic” is the major concept of the portfolio. For last, Red algae have the smallest portfolio (7461 patent families) and the technology domains that characterize the portfolio, principally, are Pharmaceuticals and Organic Fine Chemistry. “Active ingredient” is the major concept. For the Portuguese case study, IPL, and UM (academic institutions) are the major key players with three patents families, each one. Pharmaceuticals is the dominant technology domain and “culture medium” is the concept integrated in a bigger number of patent families.

In the bibliometric analysis, for Food Science Technology/Nutrition, macroalgae have a total of 731 documents and are a trend in the research. However, it is not China that has the greatest number of academic publications, but it is South Korea, Spain, and

Japan. Analysing the co-authorship between authors it was observed that the largest set of connected authors was represented by Portuguese authors. This fact emphasizes the great cooperation between Portuguese authors. The co-authorship between organizations demonstrate that the Spanish state agency CSIC is the organization with more associated documents and with a total of four links. It was also possible identify a "Portuguese Cluster", represented by different institutions. However, none of those institutions were IPL or UM, the top two assignees of Portuguese patent analysis. The co-authorship between countries show us a great network where it was possible identify different clusters. The biggest cluster (cluster 1) had a large number of Asian countries, but Spain and USA were the countries with more links. Without a doubt Spain is the leader country of the macroalgae bibliometric analysis. Spain are in the top 3 countries with most published papers, has the organization with more documents and links and is one of the countries with most cooperation with the other countries. The co-occurrence analysis using the author-keywords allow us to identify the major terms. "Antioxidant activity" is the term with major occurrences and "Functional food" is the term with major links. Those results are coherent with the potential of seaweed as an antioxidant source and as functional food, capable of improving human's health. The term "carrageenan" is also the term with more occurrences in the cluster 3 and the term is at the same time the major concept of the patent analysis.

Patent analysis results for microalgae gave us the information that microalgae portfolio has 12524 alive patent families (60 % granted and 40 % pending patents). The top IPC codes are extremely related with microorganisms and, in fact, the major technology domain is Biotechnology with 6278 patent families. As observed for macroalgae portfolio, 2017 was also the year with most applications and China the country with most patent families (21 % of all portfolio). ENN Science & Technology Development and China Petroleum & Chemical are the top two key players and both operate in the field of energy. MIT and Broad Institute, USA academic institutions, are the assignees with more pending patents and not only demonstrate the R&D of those institutions but also their strong investment in Biotechnology. Some of the major concepts, as "microalgae culture", "microalgae growth", "photobioreactor", "microalgae cultivation", demonstrate that inventions related with microalgae cultivation are a trend. For the Portuguese case study 73 % of the portfolio is maintained by the top 10 players and IPL and UP lead the ranking with two patents each. In the line with the previous results the major technology domain is Biotechnology and "culture" is the major concept.

376 documents were obtained from the bibliometric analysis for microalgae using the selected subject areas. Spain leads the ranking with most published documents (47) and other countries as Brazil, China, USA, France, and Germany have on average 32 publications and India, Portugal and Italy have on average 23 publications. The biggest set of connected items in the co-authorship between authors show us the great connection between Belgian authors. Through the co-authorship between organizations it was only possible identify one cluster with three items and those organizations were German. With this information it is possible conclude that for microalgae research institutions make an autonomous/independent work, not having a clear teamwork between institutions (nationally or internationally). From the co-authorship between countries five clusters were obtained and Brazil is the country with most documents and France and Spain are the countries with more links. Once more, Spain can be highlight for the co-authorship analysis but also Brazil and France. Analysing the co-occurrence using the author-keywords the term "carotenoids" is the term with more weight and the terms "carotenoids" and "omega-3" are the ones with most links. Cluster 4 is related with the utilization of microalgae in Biorefinery and this trend in the academic research is coherent with the trend of the results of the patent analysis, not only the major concepts are related with biorefinery, but also the top assignees for granted patent families operate in the field of the energy.

In conclusion, TS and TF have proven to be very useful and efficient tools to study/analyse not only the current state of algae market and algae academic field but also to predict its impact on the future. Still, in terms of obtained results it is important to conclude that: the seaweed patents portfolio is much bigger than the microalgae patents portfolio which also verified for the bibliometric analysis – the number of published documents for macroalgae is bigger than for microalgae. Seaweed applications are more related with Food Chemistry and Organic Fine Chemistry (in particular for Cosmetic Sector) but microalgae applications are more related with

Biotechnology, with highlight for applications in the Energy Sector. Also for the bibliometric analysis, microalgae has more leading/top subject areas (with more associated documents) – such as "Biotechnology Applied Microbiology", "Environmental Sciences" or "Energy Fuels" – in addition of the selected ones ("Food Science Technology" and "Nutrition Dietetics") than macroalgae has. China is the country that detain the macro and microalgae portfolios in the patent analysis however in bibliometric analysis we can conclude that: Spain is the country that most invested in algae studies related with food applications and/or human nutrition (a total of 154 documents); China, India, Portugal, and USA have also invested in macro and microalgae studies, allowing them to enter in the top 10 countries on both researches; most of the countries that are in ranking of both researches are European countries (Spain, Ireland, Portugal, France, Germany, Italy, and Netherlands) showing the European investment and interest in algae academic research for food purposes. The co-authorship analysis between authors shows that Portuguese authors lead in macroalgae research and Belgian authors lead in microalgae research; In terms of co-authorship between institutions, the lack of cooperation/relationship between various institutions/organizations in the microalgae case study was not observed in the case of macroalgae. Both for macro and microalgae the co-authorship between countries gave us the information of the cooperation between different countries, with highlight for Spain. "Functional food", "antioxidant activity" and "antioxidant" are important terms for macro and microalgae bibliometric analysis. It is possible conclude that algae are not only a trend for market (with different technology applications) but also academic literature, related with Food Science and Technology, is becoming a trend. Both trends are related once before any market application with food purposes previous research and scientific support is required.

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