ULPGC Universidad de Las Palmas de Gran Canaria | Facultad de Ciencias del Mar

Potential of microalgae biotechnology as a new sector for diversification in the Macaronesian Region : a techno-economic assessment

María Jiménez López

2021/2022

Tutor: Juan Luis Gomez Pinchetti

Cotutor: Antera Martel Quintana

Trabajo Fin de Título para la obtención del título en Grado de Ciencias del Mar.

DOCUMENT NAME:	Potential of microalgae biotechnology as a new sector for diversification in the Macaronesian region: a techno-economic assessment
Student name	María Jiménez López
Course	2021/2022
Title	Bachelor degree in Marine Science
Institution	Banco Español de Algas
Project	REBECA
number / code	MAC/ 1.1a /060
Tutor and cotutor	Juan Luis Gómez Pinchetti, Antera Martel Quintana

The REBECA project (MAC/ 1.1a /060) "Network of Excellence in Blue Biotechnology (algae) of the Macaronesian Region" has co-financing of 85% of ERDF Funds obtained in the 1st call for projects of the INTERREG Cooperation Program VA Spain-Portugal MAC (Madeira-Azores-Canary Islands) 2014-2020 .

María Jiménez López

Juan Luis Gómez Pinchetti

Antera Martel Quintana

Las Palmas de Gran Canaria, a 2 de junio de 2022

Table of Contents

Abstract

The blue bioeconomy emphasizes its aims on the potential of marine biodiversity and the sustainable transformation of renewable marine resources into goods and services that are just not just for the supply of human and animal sustenance, but also for a variety of other purposes across other domains. In this assessment the burgeoning industry of algae in a European framework we be discussed with special emphasis on the forward trend of microalgae along with the current possibilities of the procurance of secondary metabolites from microalgae and their high-added-value products in the pharmaceutical and nutraceutical sector. The study also reveals consumer awareness towards microalgae, with results that may be applied to other locations for diversification. Furthermore, through an economic lens, it is conceivable to diversify in the Macaronesian region exhibiting microalgae bioactive compounds with commercial interest.

Keywords: Astaxanthin; Bioactive; Bioeconomy; Biotechnology; Europe; Macaronesia; Market; Microalgae; Nutraceuticals; Pharmaceuticals; Questionnaire; SWOT; β- carotene.

Resumen

La bioeconomía azul enfatiza sus objetivos en el potencial de la biodiversidad marina y la transformación sostenible de los recursos marinos renovables en bienes y servicios que no son solo para el suministro de sustento humano y animal, sino también para una variedad de otros propósitos en otros sectores. En esta evaluación se discutirá la emergente industria de las algas en un marco europeo con especial atención en la tendencia de avance de las microalgas junto con sus posibilidades actuales de obtención de metabolitos secundarios de alto valor añadido en el sector farmacéutico y nutracéutico. El estudio también revela la conciencia del consumidor hacia las microalgas, con resultados que pueden aplicarse a otros lugares para la diversificación. Además, desde una perspectiva económica, es concebible diversificarse en la región Macaronésica exhibiendo compuestos bioactivos de microalgas con interés comercial.

Palabras clave: Astaxantina; Bioactivo; Bioeconomía; Biotecnología; DAFO; Europa; Macaronesia; Mercado; Microalgas; Nutracéuticos; Farmacéuticos; Cuestionario; β-caroteno.

1. Introduction

Seas and oceans cover more than 70% of the earth's surface and are the habitat of 80% of all forms of life on the planet. This aquatic ecosystem is responsible for the largest carbon sink in the world and the primary source of protein that feeds millions of people. The oceans regulate the climate and are the true lungs of the planet, producing 50% of the oxygen we breathe.

The ocean is a fundamental part of the development of society since it can provide many of the most essential needs of the country. Issues related to Blue Economy can offer various sources of sustainable development, such as fisheries and aquaculture, as well as opportunities for Member States.

A sustainable Blue Economy enables society to benefit from the oceans and coastal regions, while protecting the long-term potential of these natural resources. This concept supports the sustainable development of human activities and the protection of the oceans (COM, 2022).

The updated EU Bioeconomy Strategy aims to develop a sustainable bioeconomy for Europe. Thus, reinforcing local economic resilience and offering new income and job opportunities through increased innovation, circularity and market diversification. Despite the already recognized value of the potential of algal biomass, there are still knowledge gaps in the area of algal production in Europe (FAO, 2020)

Although some algae-based products, such as agar and alginates, are already on the market, most commercial microalgae-based products and derived bioactive compounds are still in the development or commercialization phase. Pigments, lipids, including omega-3 fatty acids, vitamins, toxins, and other chemical compounds have been found in microalgae.

In the vast majority of cases, the product development phase, which follows the original discovery and research/experimentation phase, is usually long and exclusive to the biotechnological or industrial subsector for which an application is intended. The "blue" component of a product decreases once it has reached the scale-up and commercialization phase, when stakeholders are no longer limited to marine biotech, but include other biotech or industrial sectors (ECORYS 2014). As a result, in many cases, the final product is no longer considered a blue biotech product, but rather a product from the application sector (food, cosmetic, pharmaceutical, etc.). Identification and recognition of mature blue biotech products is a major challenge.

In Europe, the production of aquatic plants is of recent appearance. Aquaculture production of algae is an expanding sector driven in recent years by the increased demand for algal biomass for a variety of applications such as food supplements, nutraceuticals, cosmetics, biomaterials, bioremediation (FAO, 2018).

1.1. Study Area & Data

1.1.1. Europe in numbers

Microalgae sales revenue was $3 billion in 2016 and is expected to reach $4 billion in 2022 with a compound annual growth rate, CAGR, of 4.5%. The microalgae market in Europe was 584.2 million in 2016 and is expected to grow to 761 million dollars in 2022, which is equivalent to a CAGR of 4.51%.

The European algae sector amounts to 225 companies producing macroalgae (67%) and microalgae (33%). In addition, 222 spirulina producers were identified, of which 15% are also producers of microalgae (Deloitte, 2021).

1.1.2. Blue Biotech sectors

To date, 12 Member States and 53 regions have related to blue biotechnology in their smart specialization strategies "Smart Specialization Strategy" or S3 (Doussineau et al., 2022). It is an innovation policy concept based on supporting regional prioritization in innovative sectors, fields, or technologies through the "Enterprise Discovery Process (EDP)", a bottom-up approach to reveal what a region does best in terms of its scientific and technological endowments. (Foray et al., 2011).

For all sectors of the blue economy, the transition to a circular economy opens new economic prospects. It helps establish more sustainable marine business practices, reduce waste, create jobs, and gain competitive advantage for Europe. A circular economy model also makes it possible to reduce the harmful effects of unsustainable activities on land on the seas and oceans.

Fish and macroalgae are currently the most common sources of aquatic biomass used in commercial applications such as food and nutritional supplements. Other elements are gaining popularity, and new commercial applications are currently being developed. The extraction of high-value bioactive chemicals has great market potential sectors such as nutraceuticals, medicines, and cosmetics.

Blue biotechnology is a broad term that encompasses a wide variety of activities related to research and product development. Three areas can be distinguished with different levels of maturity and characteristics:

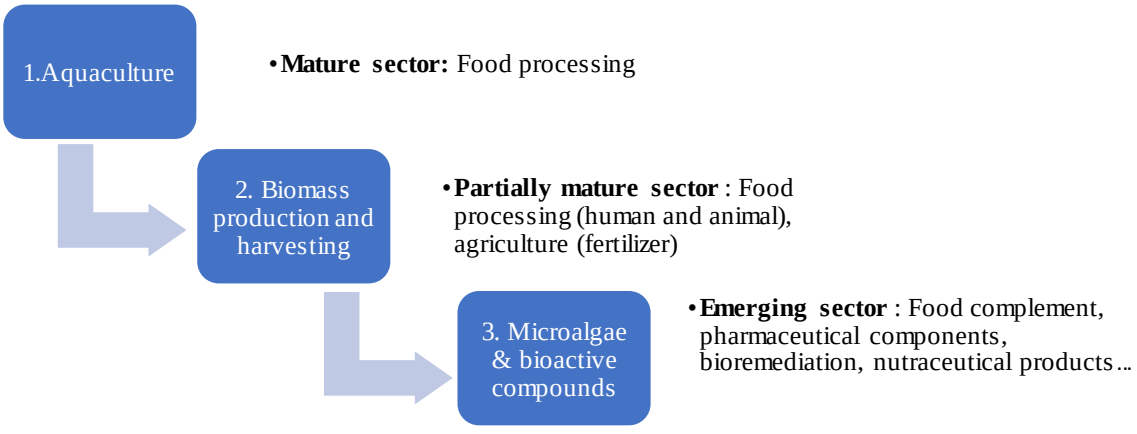


Figure 1. Sectors considered under the Blue Biotechnology concept

1.1.3. Relevant companies in the algae sector

According to the Phyconomy Data Base (www.phyconomy.net) with regards to the numbers associated to the World Algae, in 2021 there were 900 organizations although it contains extensive information, there are still some gaps, but it continues to grow as it is updated. The database also tracks subsidies and investments in the algae economy, as well as information on algal species, collection volumes and research institutes.

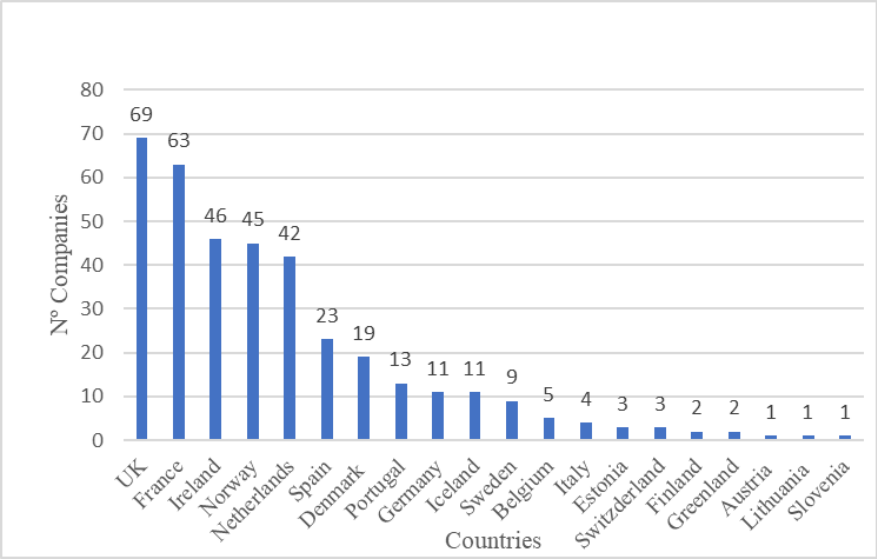


Figure 2. Number of companies for each country in Europe retrieved and modified from Phyconomy (2021)

A classification was made within the database to exclusively show the data of registered European companies. The graph in figure 2 shows the number of companies for each country ordered from highest to lowest. To complete the list, data were collected from the JRC microalgae database and from the Internet as a secondary source. This information was organized in a database maintained by the JRC and used as a basis for studies on the current state of the algae-producing sector in Europe.

Figure 3 is a visual comparison of the number of algae producing companies in Europe. Image A corresponds to the graphic representation of the JRC database processed by EMODnet and published by Frontiers in Marine Science and image B corresponds to the graphic representation of the classification offered by the Phyconomy database. In the latter, a difference between microalgae and macroalgae was not made because many companies work with both, in addition to the lack of information.

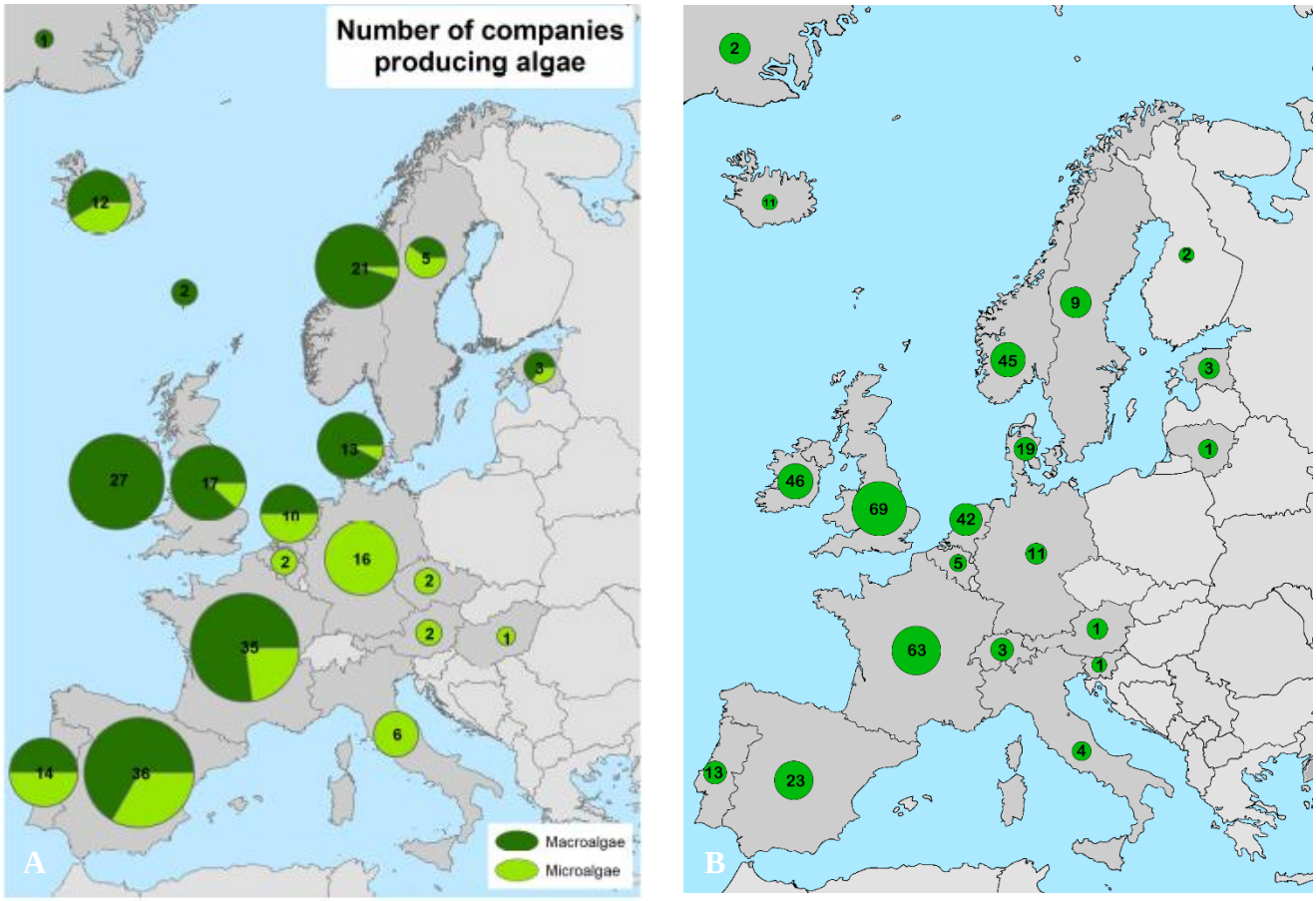


Figure 3. Comparison of the number of algae producing companies between two databases (A) JRC according to Araujo et al., 2021, and (B) according to Phyconomy

Regarding what can be observed from this comparison, according to image 3A, Spain, France and Ireland support the largest number of macro and microalgae companies followed by Norway, the United Kingdom, and Germany. Image 3B, however, positions the UK ahead, but agrees that France is one of the countries with the greatest potential in the sector, followed by Ireland and Norway.

The JRC database contains data records from 1980 to 2018, Figure 4 shows the number of currently active algae production related companies operating in Europe. The left axis represents the numerical values while the right axis represents the cumulative number of active companies up to 2018 per year (Araújo et al., 2021). The absence of specific data and information dedicated to blue biotech makes it difficult to describe and map the potential economic impact of the blue biotech sector.

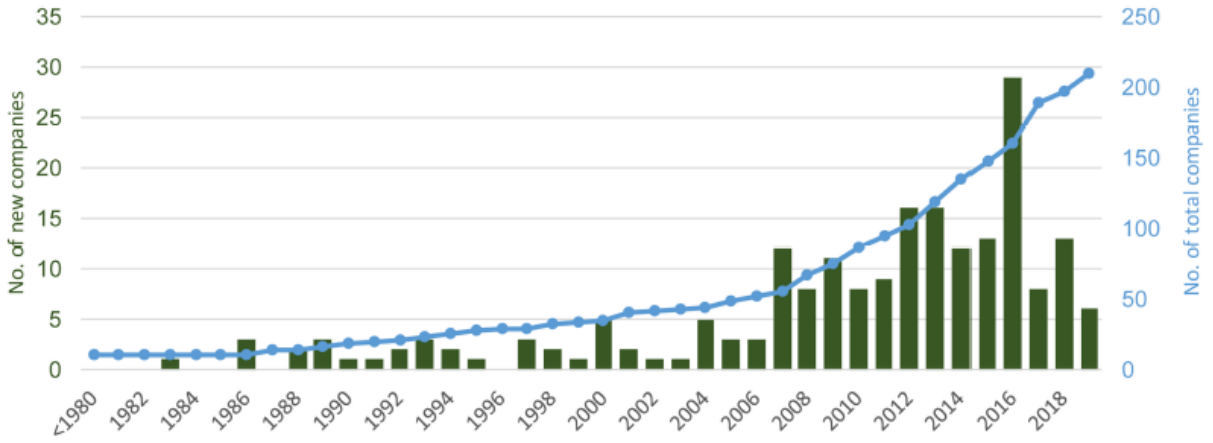


Figure 4. Comparison of the number of algae producing companies (from Araujo et al., 2021)

This trend reflects the continued interest in expanding the sector in Europe, as well as the temporary stability of some of the companies. Since about 1980, the number of new algae production companies has been increasing steadily, demonstrating the dynamism and growth potential of the sector. This pattern needs to be looked at, as many other companies have closed or diverted operations over the years. It should also be noted that the graph only includes data up to 2018, so post-crisis data is not included19. In the European bioindustry landscape, several studies have highlighted the potential of algae biomass production as an economically sustainable activity (Buschmann et al., 2017; Hasselström et al., 2018).

However, several constraints continue to hamper the growth of the sector, the most significant being the modest size of the algae commodity market in Europe, the irregularity of the annual supply of biomass, and the current state of technological advances in production and processing of the biomass.

1.2. REBECA-CCT

REBECA-CCT aims to build on the work done in the previous REBECA (Network of Excellence in Blue Biotechnology) project in order to promote and incentivize the Microalgae Biotechnology industry in Macaronesia. Its geographical extent is restricted to the Canary Islands, Azores, Madeira, Cape Verde, and Mauritania archipelagos.

Expanding the number of strains and exploring those already identified and cataloged as new sources of metabolites of interest are among the actions planned; consolidating work teams and action protocols; improving infrastructure and equipment; creating common support services for all the Network's collections (taxonomy, cytometry, biochemistry, cultivation and processing technology, application development, and so on); and improving the services provided to technological centers are also among the actions planned. Ensuring the quality of the biological capital delivered by obtaining the necessary certifications and working with European regulatory bodies (Instituto Tecnológico de Canarias, 2022)

1.3. Objectives

Regarding the geographical scope, the assessment focuses on the EU territory, with its own collection of data on the economic potential that arise directly from the sectors identified as priority with a future perspective. This report shows and analyzes the results of a market study on an european scale to identify the biotechnological and economic potential of bioactive substances obtained from microalgae and cyanobacteria. The aim of this asessment is to identify bioactives which are necessary as the main facilitators of innovations for the bioeconomy for the diversification and development of the biotechnological sector in the chosen area, the Macaronesian region, in accordance with the objectives of the Projects of the Interreg-Mac program REBECA (MAC/1.1.A/060) and REBECA-CCT (MAC/1.1.B/269).

The study asks three questions:

(1) Which sectors will be most relevant in the next 10 years?

(2) What species of microalgae with applications in these sectors contain bioactive substances of economic interest?, and finally,

(3) Is it conceivable to diversify in the Macaronesian region with those microalgae that have biotechnological potential, as determined by the techno-economic evaluation?

2. Methodology

This section reflects the market research carried out to identify bioactive substances of economic interest, therefore makes available the data collection to subsequently interpret them, define the characteristics of the sector and using of all the information that will be useful for future decision-making. The study is covered from the approach of the three questions posed in the introduction and it will be structured in the methodological flow scheme outlined in Figure 5 which includes a survey as a primary source, a SWOT analysis as an economic tool and a cloud of main concepts based on a specific algorithm as well as secondary sources.

Figure 5. Flow diagram considering the methodological scheme

2.1. Survey

An exhaustive "first- hand "market research was carried out based on a primary research method which involves the observation of the consumer/user throughout a detailed survey where costumers were asked directly for their opinions and preferences from which qualitative data is obtained and processed for subsequent SWOT analysis with their respective evaluation. Once the potential sectors are available, the rest of the evaluation will be developed by contrasting sources of information and previous experience in the laboratory.

Questionnaire Design

Most of the researching activity consists of filling some knowledge gaps by determining the knowledge, perception, and acceptance that consumers have regarding microalgae, what they are, or the health benefits that are attributed to their consumption, or their possible applications. among other issues. To do this, a specific questionnaire was designed for the study, which included 15 open and closed questions providing options for the citizens surveyed to reflect their opinion or pattern of behavior. The questions could be divided into two sections: (i) personal questions, including the educational/professional level and the frequency of use of algae-based food supplements, or if you consume natural foods that are beneficial to health, etc. (ii) Specific questions, in relation to algae, but more about microalgae were included in the survey in a visual way as ordered from highest to lowest according to the importance of biotechnological applications according to their knowledge or slightly more technical questions. in which proposals had to be classified as very important, important, or

irrelevant. To conclude, the respondents were asked to comment on what product derived from microalgae they would demand if they belonged to a business sector. The latter was regarded as a free-form response.

Survio (open source specific software) was utilized to develop the survey. I watched numerous training videos on how to run the program in order to get a good survey. I designed the questions to satisfy the study's goals so that the results could be assessed in a way that was tailored to each single question, allowing for a more accurate interpretation. The following links will lead users to the surveys:

European survey excluding Spain

https://www.survio.com/survey/d/A1I5R8N4B9T2N3U1A

Spanish survey

https://www.survio.com/survey/d/Z4F6B5Y4W9R3P3A7B

The questionnaire was distributed online by formal e-mail from the Spanish Bank of Algae and through communication tools such as WhatsApp groups. For the recipients, an Excel was made with more than 100 emails belonging to scientific companies both nationally and internationally. In addition, the contacts were classified according to their locality and their sector. The Excel included 115 Spanish contacts (left) and 109 European contacts excluding the Spanish population (right)

Table 1. Example of contacts classified by sector. Caption extracted from the Excel sheet

49	cjimenez@algenex.com	Biotecnología Sanitaria	Madrid			r.schubert@hszg.de	Biotecnología	Alemania
50	info@allinky.com	Biofarmacia	Madrid			t.wiegert@hszg.de	Biotecnología	Alemania
51	italfarmaco@itfsp.com	Biofarmacia	Madrid			FSE@foodsupplementseurope	Nutracéutica	Bélgica
52	bdevelop@itfsp.com	Biofarmacia	Madrid			global@spcare.pt	Farmacéutica	Portugal
53	lromero@altals.com	Inversión/capital de riesgo	Barcelona			infor@fhc.pt	Farmacéutica	Portugal
54	comunicacion@ams-lab.com	Biofarmacia	Lugo			basi@basi.pt	Farmacéutica	Portugal
55	garciasaa@aptusbiotech.com	Biotencología sanitaria	Madrid			info@overpharma.pt	Farmacéutica	Portugal
56	info@aquiloncyl.com	Biotecnoligía	León			.labesfal@labesfal.pt	Farmacéutica	Portugal
57	isanjose@aragon.com	Biofarmacia	Zaragoza			farmaciagoncalvesmortagua	Farmacéutica	Portugal
58	archivel@archivelfarma.com	Biotecnología sanitaria	Barcelona			office.vienna@cslbehring.com	Biotecnología	Austria
59	contactazmedical.astrazeneca.com	Astrazeneca	Madrid			investor.relations@amgen.com	Biotecnología	Bélgica
60	aaguado@solutexcorp.com	Nutracéutica	Madrid			amgenmediarelations@amgen.	Biotecnología	Francia
61	tammy.ter@mail.ucv.es	Biotecnología	Valencia			returns@bayer.com	Biotecnología	Alemania
62	mabel.loza@usc.es	Grupo de investigación	A coruña			contact@france-biotech.org	Biotecnología	Francia
63	info@aldo-union.com	Laboratorio farmacéutico	Barcelona			altorfer@swissbiotech.org	Biotecnología	Suiza
64	edurne@bestmedicaldiet.com	Nutracéutica	Sevilla			guillem.vals-garcia@eda.admin	Biotecnología	Suiza
65	m.fernandez@biomarmt.com	Biofarmacia	León			manuel.baader@boehringer-ing	Biotecnología	Alemania
66	a.castro@biomarmt.com	Biofarmacia	León			.kevin.dalgaard@boehringer-ingelheim.com		Alemania
67	info@biotb.org	Cluster biotecnológico	Islas Baleares			christian.thomsen@boehringer-ingelheim.com		Alemania
68	biorizon@biorizon.es	Biotecnología	Almería			oliver.kast@boehringer-ingelhe	Biomedicina	Alemania
69	bionos@bionos.es	Biofarmacia	Valencia			emilio.erazo-fischer@boehringe	Biomedicina	Alemania
70	info@bioseqs.com	Biotecnología	Valladolid			maria_antonietta.impagnatiello	Biomedicina	Austria
71	direccion.cicytex@juntaex.es	Centro de investigación	Badajoz			dpoit@chiesi.com	Farmacéutica	Italia
72	angelc@orgc.csic.es	CSIC	Madrid			integratoriitalia@unionfood.it	Suplemento aliment	Italia
73	jm.perezdelalastra@csic.es	CSIC La Laguna	Tenerife			info@biovegan.de	Alimento BIO	Alemania
74	jjfercas@ull.edu.es	Productos Naturales	Tenerife			.assoerbe@assoerbe.eu	Alimento BIO	Italia
75	elenapnf@gmail.com	Medio ambiente	Tenerife			info@sanutri.com	Nutracéutica	Francia
76	javiervina@cultiply.es	Biotecnología industrial	Sevilla			info@lns-privatelabel.com	Nutracéutica	Francia
77	javiervina@cultiply.es	Biofarmacia	Barcelona			informations.export@nutergia.	Nutracéutica	Francia
78	contacto.alimentacion@imdea.org	Fundación alimentación	Madrid			masivet@ab-science.com	Farmacéutica	Francia
79	pharmamar@pharmamar.com	Biofarmacia	Madrid			welcome@arctoris.com	Biotecnología	UK
80	clientes@actibios.com	Nutracéutica	Madrid			info@crisprtx.com	Biomedicina	UK
81	suravitasan@suravitasan.com	nutracéutica	Guipuzkoa			contact@carbios.fr	Biotecnología	Francia

2.2. SWOT Tool

The Swot analysis is an effective planning tool that companies use to guarantee that they have a clear goal based on a thorough grasp of a region's strengths and capability. A SWOT analysis contrasts a region's competitive advantages—those indigenous assets that make it unique or successful in the national and global economies—with the internal and external variables that might prevent it from reaching its full potential. Developing the strategic direction and implementation plan to promote regional economic vitality requires determining and analyzing what the region already has that could be better leveraged to build growth capacity, including competitive cultural, economic, technological, intellectual, and physical assets (U.S. Economic Development Administration, 2020)

The following terminology are typically used to describe the aspects of a SWOT analysis:

• **S**trengths are a region's relative competitive advantages, and they are usually internal in origin.

• **W**eaknesses are a region's comparative competitive disadvantages, which are usually internal.

• **O**pportunities for regional betterment or progress, which are usually external in character.

• **T**hreats are chances or opportunities for negative consequences on the region or regional decline, which are usually external in character.

The SWOT tool will be used in the current study to synthesize and summarize the most important information obtained through the surveys in order to see more visually if the use of microalgae as a biotechnological sector represents an economic advantage, as well as recognize the potential disadvantages and threats facing this marine sector. If the benefits outweigh the drawbacks, diversifying this market to Macaronesia will be seen as a wise business decision.

2.3.Word Cloud

Word clouds provide a visual representation of frequent terms and display how many times they appear in the literature. Font sizes are used to convey this. Larger font sizes refer to words that appear more often than smaller font sizes (Helbich et al., 2013).

In the WordCloud created for this study, several academic journals are published which focus on the science and techniques involved in market research. These would be of particular interest to the companies implied - not so much for the " market research data" that they contain but for the discussion of market research methodology. These papers used as a secondary source, will show the most scientific view of the matter and whether nutraceuticals and pharmaceuticals are really the sectors of greatest interest for the future, as the survey carried out assumes. Several articles, which are finally included in the Reference list, have been collected and a word cloud has been drawn. The bigger a word is in the graphic created, the more frequently it appears in the raw text being examined. Word clouds are becoming more popular as a simple technique for identifying and understanding the primary substance of documents, commonly known as keywords. For the wordcloud's creation, sources were chosen based on their research and content quality. Only papers with a competent experimental design and accurate data collection were included

3. Results & Discussion

3.1. Survey results

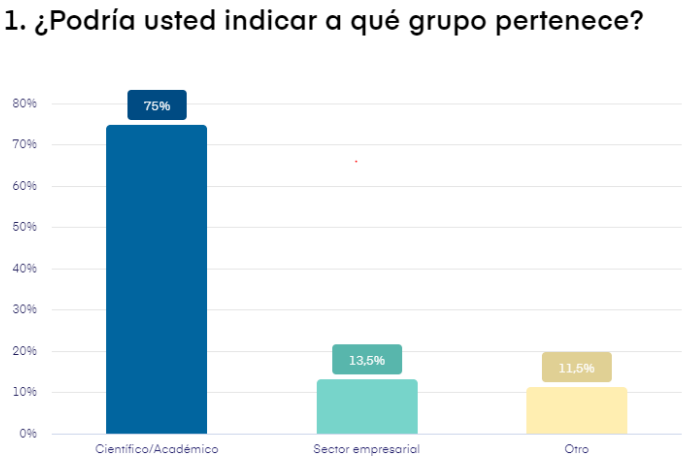
Once the survey was sent to the contact list, it was active for 3 months. A total of 115 responses were obtained, 96 from the Spanish survey and 19 from the European one. The little success of the European survey may be due to the fact that it was sent from a Spanish mail and did not appear as priority mail in the recipient. The answers obtained in most of the questions of both surveys followed the same trend, however, due to the small sample in the European survey, the treated results of the national one are shown and those answers in which different and significant data from the international survey were obtained will be compared and discussed in addition to the most relevant data

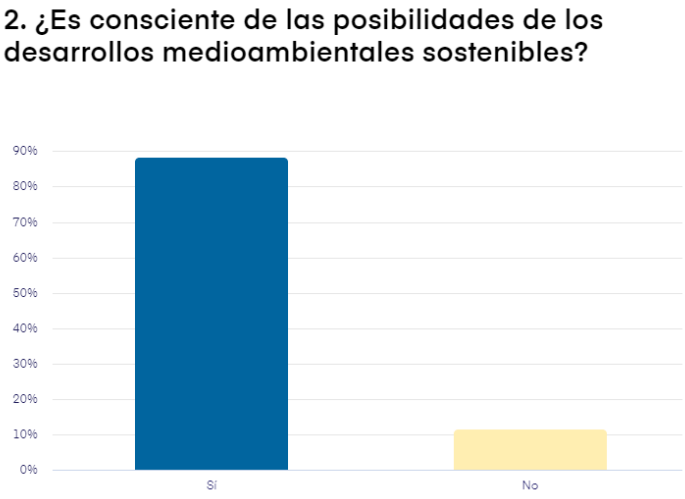
3.1.1. Q1: Which sectors will be most relevant in the next 10 years?

The survey, whose length was 15 questions, was distributed translated into English to reach European respondents and thus have a broader perspective of the current "consumer" situation. In general, it could be said that the answers between the different population samples (European and Spanish) obtained practically the same answers with similar percentages. This is a good indicator when it comes to being able to establish common objectives without the need to segment the market with respect to the consumer's region of residence. However, there were differences in some questions which will be discussed later.

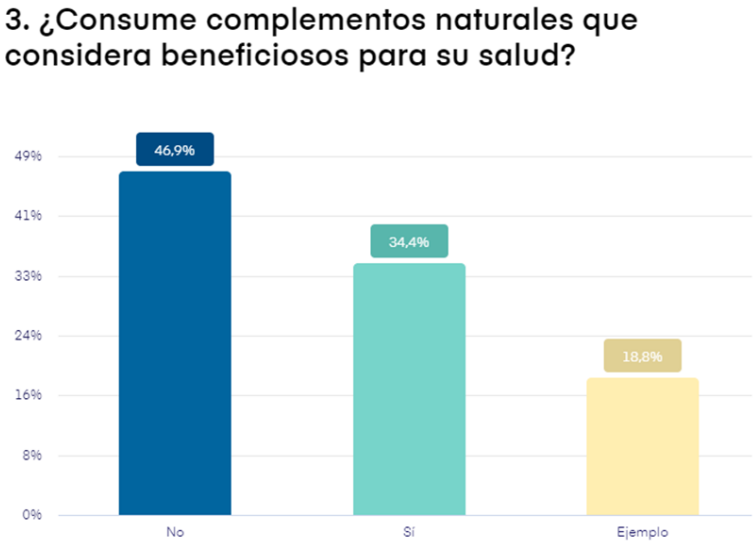
The main objective of the survey was to identify the sectors/fields that will have the greatest demand in the next 10 years, in addition to knowing the profile and knowledge of the consumer. The technical questions asked are intended to help to carry out a more in-depth analysis of the situation using the SWOT tool.

The questions related with the survey “consumer knowledge about bioactives from microalgae” also appear in spanish because this survey was included in the REBECA-CTT project.

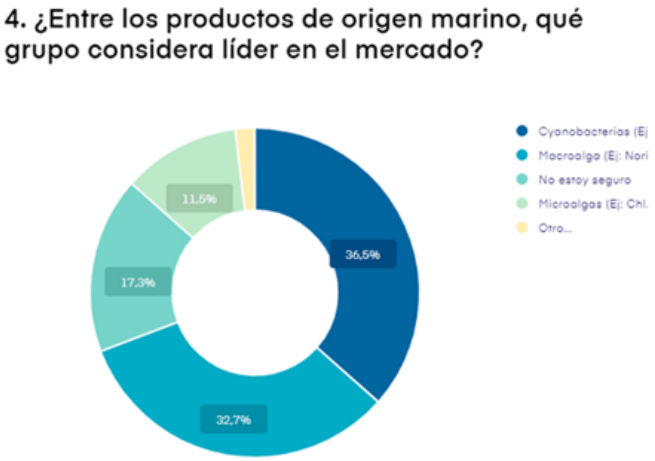


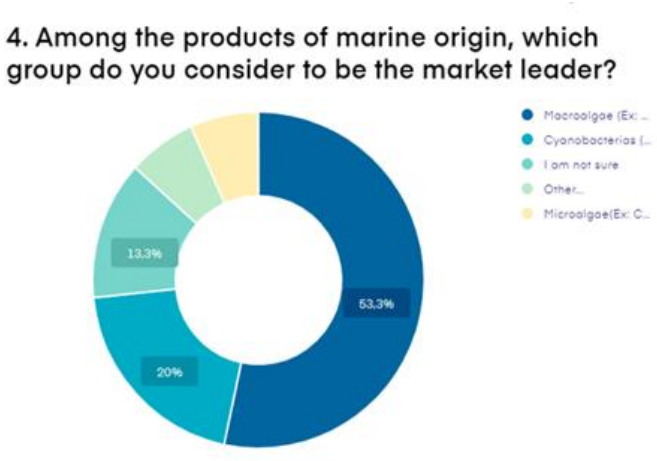


From the surveys it is known that the majority of the surveyed sample, approximately 75% both in Europe and in Spain, belongs to the academic scientific group while 13% corresponds to the business sector and the rest indicated the "*other*" option. More than 80% are aware of the possibilities of sustainable environmental developments, which makes sense given that, as shown in question 1, the majority of respondents have a bachelor's, master's or even doctorate degree. In the case of question number 3 : *"Do you eat natural foods that are beneficial to your health?"* , it was possible to comment on examples in the affirmative case , where the most repeated answers were vitamin complexes, Omega 3, *Spirulina*, *Fucus* and PUFA's .



In terms of the leading market group, question number 4 was asked to select between macroalgae, microalgae, cyanobacteria and another, offering an example of each of the options. Also provided the ability to mark not sure to be a valid answer. In this case, there were differences between the European and Spanish samples. Positioning Spain to the cyanobacteria in the first place and Europe to the macroalgae. An interesting fact was the % of the microalgae group, reaching 17.3% in Spain while in Europe it did not reach 10%.

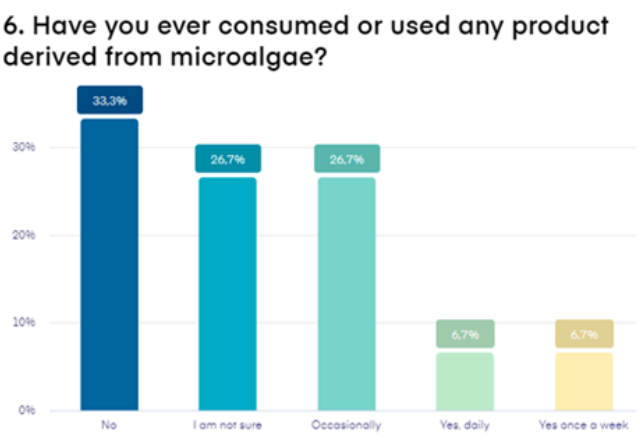




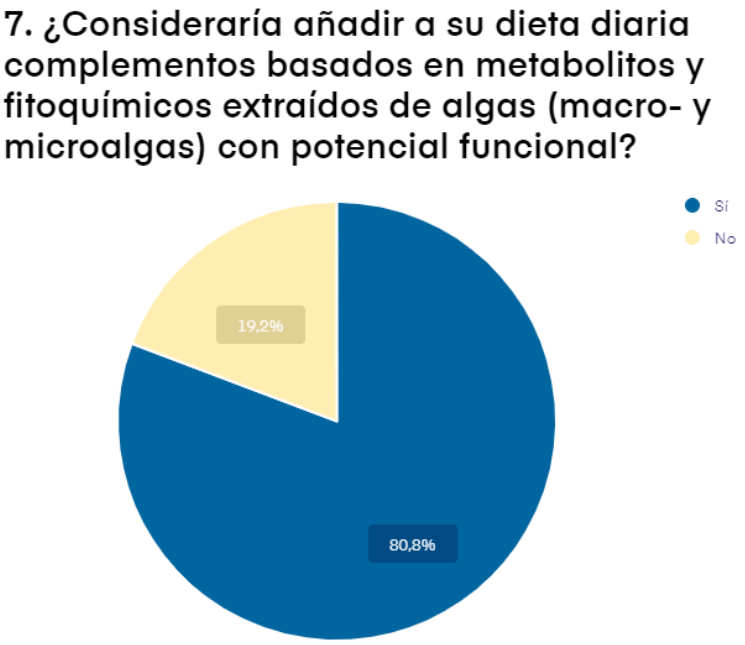
The lower percentage in microalgae is also due to the fact that there are a limited number of microalgae strains that can be used in food. Microalgae must be marketed in the EU under the Novel Food Regulation Regulation (EU) 2015/2283, which defines a novel food as one that has not been consumed in a significant quantity in the EU before May 15, 1997. Spirulina (cyanobacteria) is not subject to this restriction due to its long history of use and is one of the most frequent for food applications and consequently the most commonly known.

Responding to one of the main objectives set for the survey, question number 5 should be ordered from highest to lowest according to knowledge and interest among the aquaculture or animal feed, human consumption, nutraceutical, pharmaceutical, cosmetic, biofertilizer and energy: *"Some species of microalgae with biotechnological applications are used in different commercial sectors"*. In Europe the order was: Pharmaceutical > Human consumption > Cosmetics > Nutraceutical > Animal feed > Biofertilizer > Energy. In Spain the result was: Nutraceutical > Human Consumption > Pharmaceutical > Cosmetics > Animal feed > Biofertilizers > Energy .

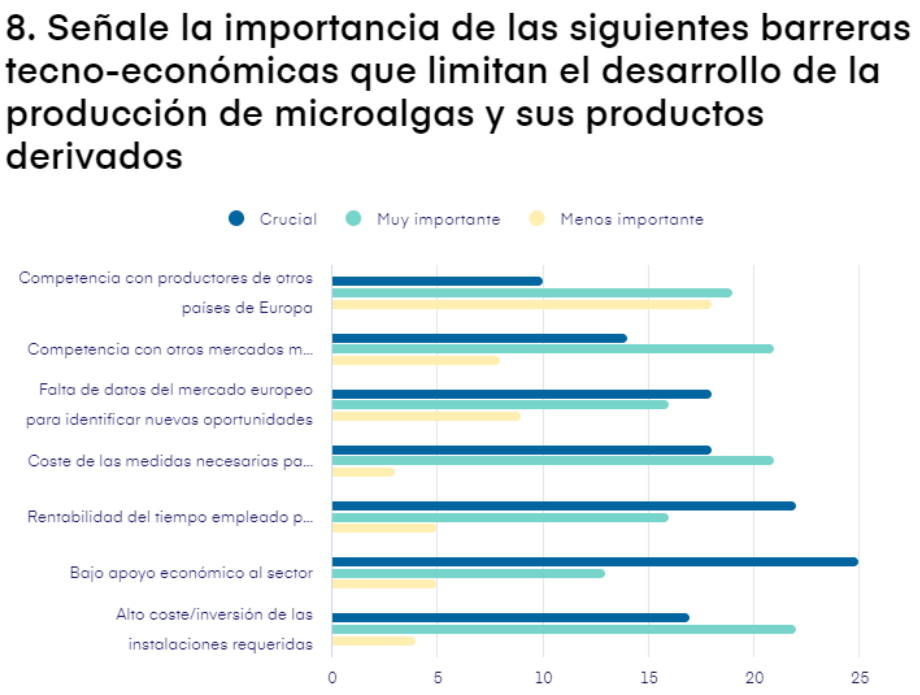
Although the order was not exactly the same, the results of both surveys coincide in that the sectors with the greatest potential of the seven offered are pharmaceuticals, nutraceuticals, human consumption and cosmetics. One of the most personal questions was number 6, in which disparate results were also obtained.

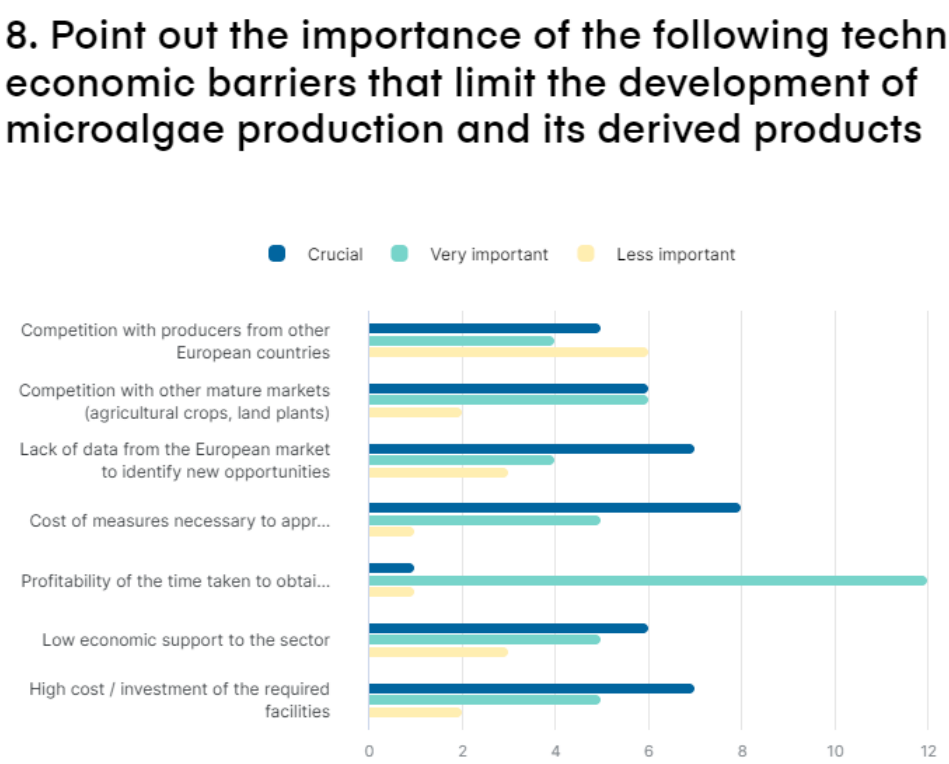


The main difference is found in the percentage of consumption given that in the case of Spain the value doubles *"occasionally"* compared to the European sample. Although the value of *"Yes, once a week"* is quite even. Although it is not the majority, there is a significant percentage that does not know if they consume it in their daily life, which implies a lack of knowledge about the substances/components that are currently consumed.



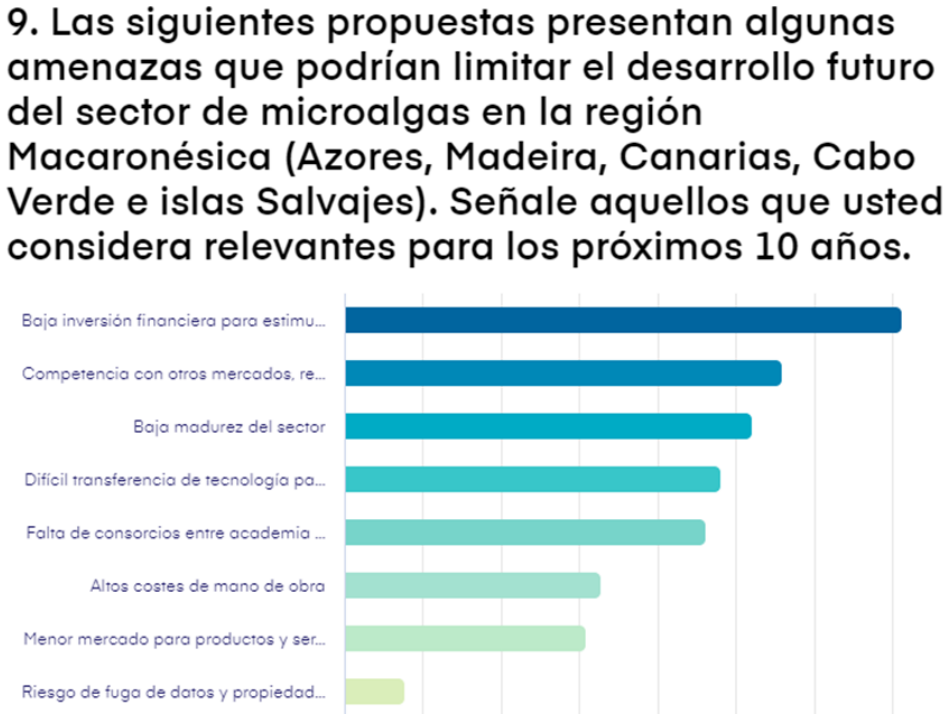
The next question in which different opinions were collected was number 8, a much more technical question because it was necessary to know the degree to which the techno-economic barriers mentioned limit the development of the production of microalgae and derivatives.

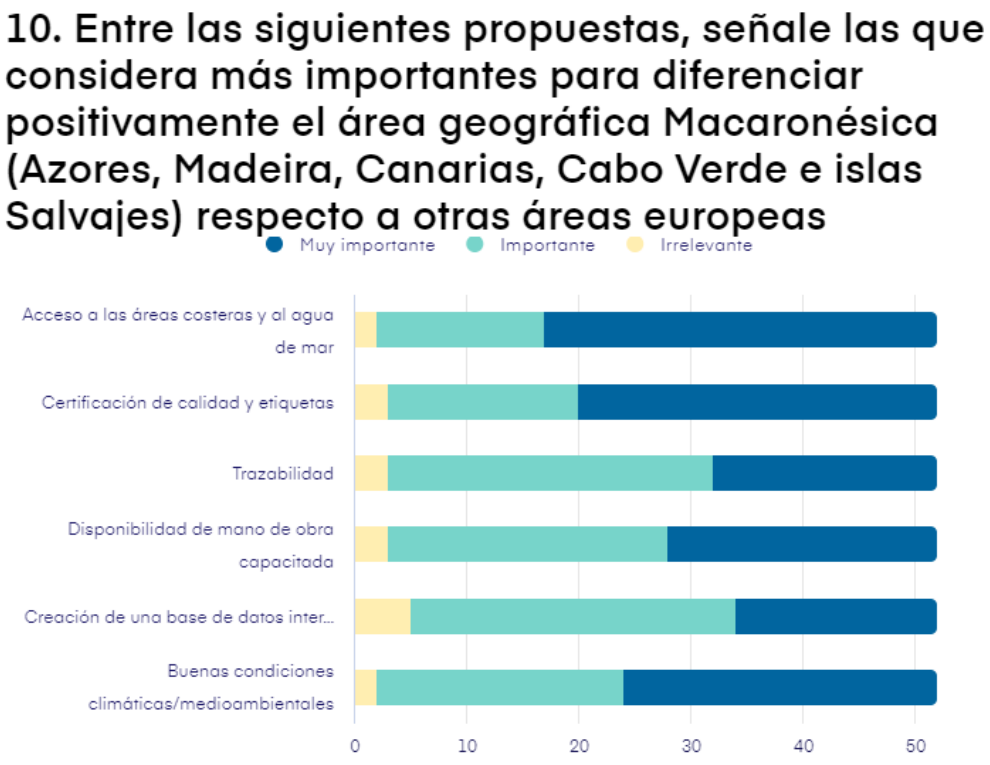




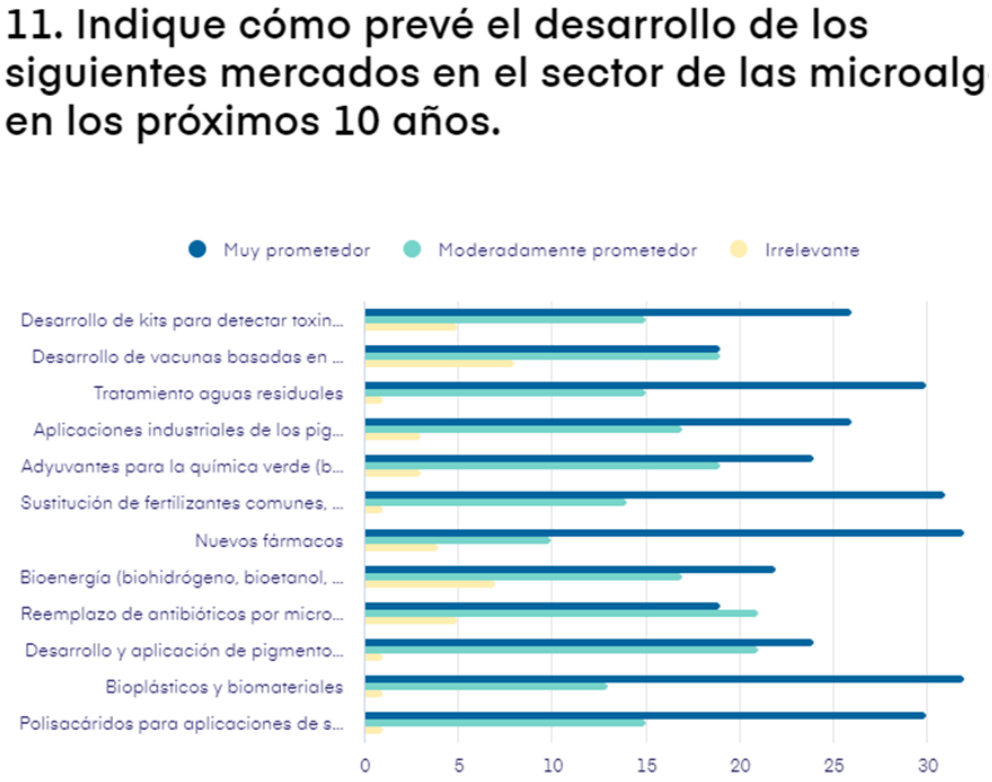
In Spain, the majority of those surveyed considered the low economic support for the sector to be a very important barrier, while in other European countries it really does not represent a limit to the development of the sector. This is because other countries receive more financial support compared to Spain. However, Europe did consider the profitability of the time spent to obtain a high value-added producer to be an important factor, coinciding with Spain. Both surveys attributed the barrier considered *"less important"* to competition with producers from other countries.

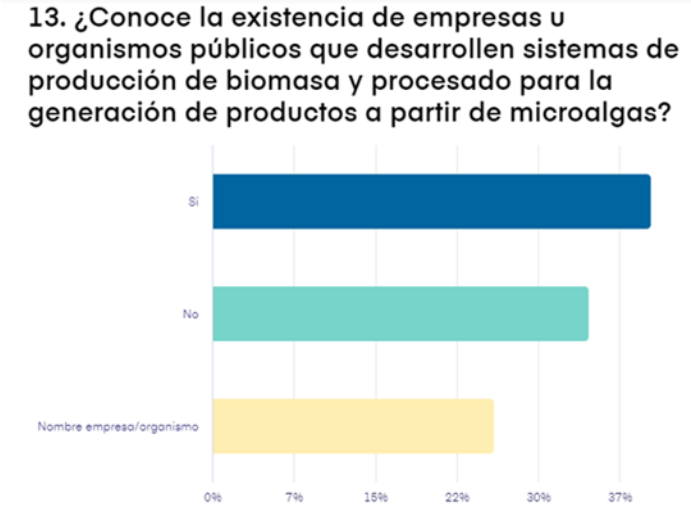
Question number 9 was related with the threats and it was used for the elaboration of the SWOT.

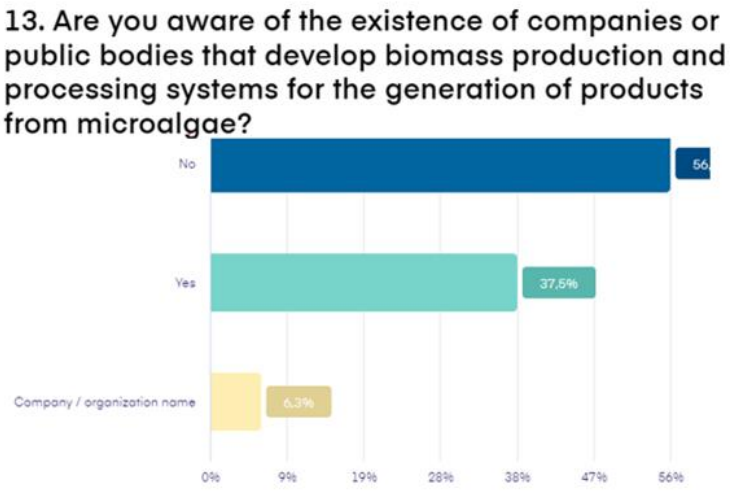




Regarding the consumer's knowledge of bioactive substances, the following questions were asked:

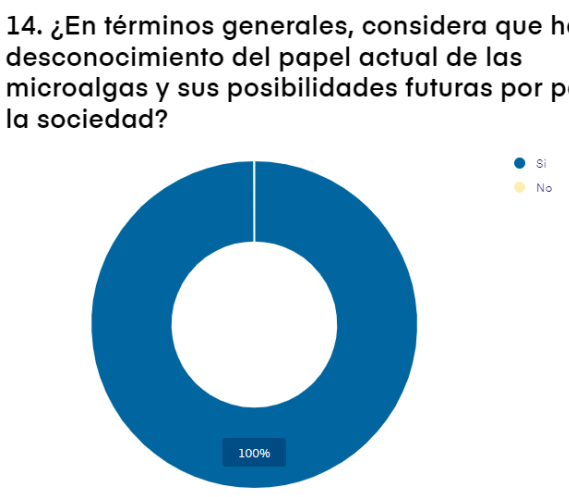


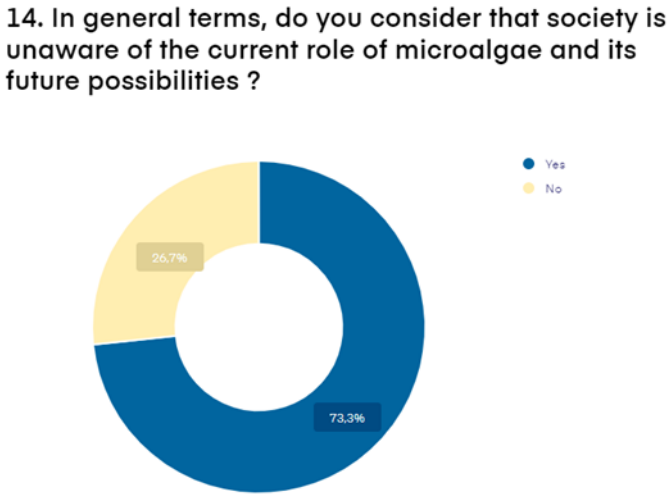




The answers obtained were not related in any way between the two surveys. In Spain, at least 37% of the population (with respect to the significant sample) knows some company or public bodies related to the algal sector. Unlike other European countries where more than half of the population do not know a company related to the sector. In this question, they could comment on which company they knew. In the case of Spain: Nutergia , BEA, Algalimento , AlgaEnergy , Fitoplancton Marino, MARE, Algaplus , Allmicroalgae , UMa . In the European survey, only two respondents specified a name: A4f and Allmicroalgae .

In general terms, after what was visualized in the answers to the previous questions and specifically in question number 14, the existence of a great lack of knowledge on the part of society regarding the current role of microalgae and their future applications is considered. Reaching 100% in the Spanish survey and almost 75% in the European one





15. Si usted pertenece al sector empresarial, por favor indique en qué campo se encuentra su empresa y qué producto/s derivado/s de microalgas demandaría. Si lo desea, puede facilitar el nombre de la empresa.

RESPUESTA	RESPUESTAS	RATIO
	43	82.7%
Sector farmacéutico. Cualquier medicamento o producto oto o dispositivo médico que mejorará a	1	1.9%
produtor de spirulina	1	1.9%
Laboratorio Farmacéutico	1	1.9%
Industria Minera: tratamiento de aguas residuales producto de la transformación de la materia prima.	1	1.9%
Farmacéutica. Nutraceuticos. De todas maneras, incluso para el personal que trabajamos en el sector, hay muchos desconocimiento sobre los potenciales usos de las microalgas	1	1.9%
Estudiante	1	1.9%
Espirulina, chlorella...	1	1.9%
Biotecnología Industrial y ambiental: biopolímeros como el PHB, biofertilizantes y para tratamiento de residuos. Centro Tecnológico ITENE	1	1.9%
Agricultura e aquacultura	1	1.9%

In order to investigate more about the demand for products enriched with microalgae, consumers were asked one last question, totally optional to answer: "*If you belong to the business sector, please indicate what field your company is in and what product /s derivative/s of microalgae would sue"*

As expected due to the statistics of the number of answers obtained, the Spanish survey received more answers in this last question where the pharmaceutical, nutraceutical, spirulina production and industrial and environmental biotechnology sectors such as biopolymers (PHB) biofertilizers and products stood out. for waste treatment. The European survey mainly focused on the demand for products for human and animal health or what is the same, nutraceuticals.

After analyzing and commenting on the results of the surveys carried out, it is concluded that the pharmaceutical and nutraceutical sectors, among which we can include cosmetics and biomedicine, will be the most emerging sectors for the next 10 years.

3.2. SWOT Analysis

The strengths and weaknesses of the SWOT or SWOT analysis present internal characteristics of the biotechnology sector where Macaronesia has corporate advantages and disadvantages, while the opportunities and threats, however, represent the external factors that favor or hinder biotechnology-based innovation and commercialization in the Macaronesia . This SWOT summarize the collected data in the primary research carried out within the survey.

Figure 6. SWOT Analysis

3.3. Terminology Cloud

3.3.1. Q2: What species of microalgae with applications in these sectors contain bioactive substances of economic interest?

Unlike question number 1 in which a primary research method was mainly used, to answer this question, the study will pay attention to the results obtained through the market research carried out in the previous section and it will be contrasted with a secondary source of data, particularly academic journals.

Given the enormous database utilized for comparison, a word cloud was produced, Figure 7, using an opensource software called *"Wordcloud"* that emphasized the primary themes within the papers, revealing the following main keywords: nutrients, species, microalgae, nutraceutical, pharmaceutical, treatment, therapeutic, and biomass as main keywords.

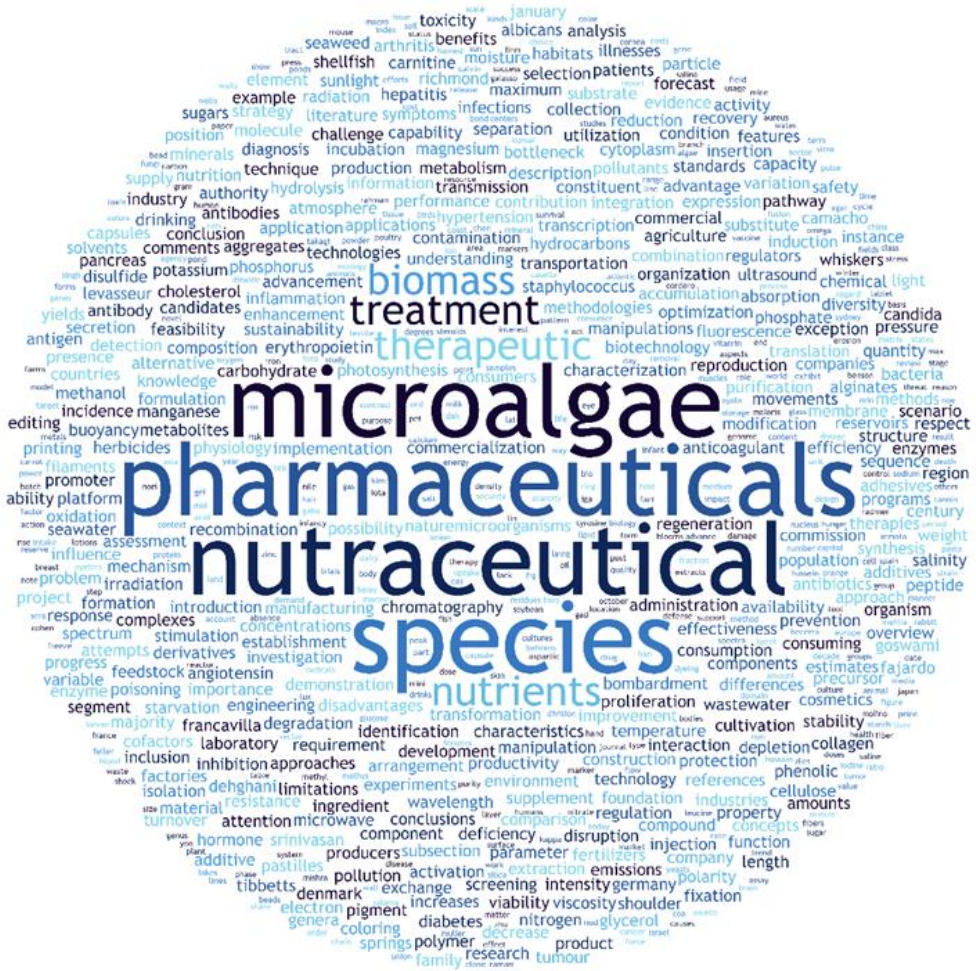


Figure 7. Main concepts, word cloud of the European scientific publications related to microalgae bioactive compounds (references selected are included in the Reference list).

3.3.2. Biotechnological applications of microalgae biomass in sectors illustrated by the Word Cloud

The possibility for a broader diversity of microalgal species that have been used in human applications is well-founded. Table 2 highlights many of the most frequent microalgae pigments that are favorable to human health, the applications of microalgae biomass and bioproducts produced from it. In the subsections below, several uses of microalgal biomass in various areas such as nutraceutical and pharmaceutical are described.

3.3.2.1. Nutraceuticals

Nutraceuticals are food ingredients that not only enhance the diet and moreover assist in the prevention and treatment of illnesses and disorders. Recent publications have examined the latest advances in biotechnological microalgae development and supply, with an emphasis on their application for nutraceuticals (Chew K.Wet al.,2017) . Italy and Spain are the leading nations publishing nutraceuticals in Europe (Rumin, J et al., 2020)

Other research papers have also shown that consuming microalgae bioproducts is beneficial to human health. Hamed (2016) mentioned that microalgae such as *Chlorella* sp., *C. vulgaris, H. pluvialis, D. salina* are commonly used in the production of a wide variety of nutraceutical products. Carotenoids, such as β-carotene, astaxanthin, fucoxanthin, zeaxanthin, and lutein, are also valued for their nutraceutical and functional qualities. The utilization of astaxanthin, lutein, and green (microalgae) to treat disorders is the target of most carotenoids research. Consequently, to its high- popularity as a nutritious meal in supermarkets, chlorella and spirulina have led the global microalgae nutraceuticals industry.

Humans consume microalgal amino acids and protein as a nutraceutical food source. The ingestion of single-cell protein meets the daily protein requirement. MSAs, likewise, aid in the removal of free radicals from the body and provide protection against UV radiation (Sun et al., 2020). Astaxanthin in food reduces the formation of undesirable germs, protects against UV radiation, inflammation, and malignant cells in the human body. Microalgae, according to Georgakopoulou (2018), include omega-3 (DHA, EPA, and a-linolenic acids) and omega-6 PUFAs (linoleic acid, arachidonic acid, glinolenic acid). Carbohydrate eating aids in the enhancement of health and has immune-stimulating properties in humans (Sathasivam et al., 2019).

3.3.2.2. Pharmaceuticals

The search for pharmacologically active chemicals in microalgae, particularly cyanobacteria, has risen in popularity in the recent decade.

Microalga-based pharmaceutical goods aid in the reduction of immuno-stimulating activity, immune defense system improvement, pro-vitamin source, malnutrition, nutritional deficiencies, metabolic syndrome (diabetes, obesity, and nonalcoholic steatohepatitis), cardiovascular diseases, cancer, macular neurodegeneration, cataract,Alzheimer's disease, depression, schizophrenia, fetal malformation, pregnancy complications, dental diseases, as well as bacterial, parasitic, brain damage and anti-cancer properties, and so on… In humans, it also aids in the prevention of tumorigenic cells.

Furthermore, the microalgae biomolecules have anti-wound, anti-peptic ulcer, and anti-constipation properties.

Microalgae, like nutraceuticals, are an innovative biotechnological resource for the production of high-value biomedical products like recombinant proteins (vaccines, cytokines, hormones), biologically active polysaccharides, lipids, or pigments (carotenoids, phycobiliproteins), which could be used for disease treatment, diagnosis, and prevention. β -Carotene, fucoxanthin, zeaxanthin, violaxanthin, lutein, alloxanthin, and other carotenoids have shown important pharmacological activities in improving fertility (astaxanthin), preventing macular degeneration (lutein and zeaxanthin), rheumatoid arthritis, cardiovascular diseases, neurodegenerative diseases, obesity (fucoxanthin), and cancer. PUFAs have been researched for their ability to prevent and improve cardiovascular disease, cancer (anti-metastatic activity, antiangiogenic activity, and chemo- and radio sensitization of tumor cells), type 2 diabetes, inflammatory bowel disease, asthma, arthritis, skin disorders, depression, and schizophrenia.

Toxins, which are pharmacologically active chemicals generated by microalgae (particularly dinoflagellates and diatoms) and cyanobacteria possessing harmful effects on human health, should be highlighted. Toxins have gained popularity as pharmacological tools, and they may be beneficial in the development of novel bioactive molecules.

This domain is also closely linked to the pharmaceutical industry's economic and commercial goals, which drive the development of microalgae-based drugs.

Table 2: The biotechnological applications among many high-value active compounds synthesized by various microalgae. Modified and summarized from Academical journals (Palozza et al., 1996; Mudimu et al., 2017; Saini et al., 2020; Koyande et al., 2019; Li et al., 2019c; Sathasivam et al., 2019; Sarkar et al., 2020 ; Tibbetts et al., 2015b;)

Main Bioactive compounds	Microalgae	Functions
β- carotene	*Chlorella zofingiensis* *Dunaliella tertiolecta* *Dunaliella salina* *Spirulina máxima*	Feed, nutraceuticals, pharmaceutical and cosmetic industries; antioxidant properties; modulates gene expression in keratinocytes; work as pro-vitamin and helps in the synthesis of vitamin A.
Astaxanthin	*Haematococcus pluvialis*	UV rays and photooxidation are mitigated by the shielding effect
Fucoxanthin	*Isochrysis aff. galbana* *Cyclotella cf. cryptica* *Cylindrotheca closterium* *Mallomonas sp. SBV13* *Nitzschia cf. carinospeciosa* *Odontella aurita* *Paralia longispina* *Phaeodactylum tricornutum*	Chemotherapeutic potential
Canthaxanthin	*Coelastrella striolata* var. *multistriata*	Nutritional supplement, natural antioxidant, food dyes

Continued

Canthaxanthin and Lutein	*Chlorella vulgaris*	Protect against oxidative stress, cancer, and chronic obstructive pulmonary disease by reducing hyperlipidemia and hyperglycemia
Lutein	*Auxenochlorella protothecoides* *Chlorella protothecoides* *Chlorella pyrenoidosa* *Chlorella sorokiniana* *Chlorella sp.* *Coelastrella sp.* *Galdieria sulphuraria* *Parachlorella kessleri* *Scenedesmus almeriensis* *Scenedesmus sp.* *Scenedesmus bijugus* *Vischeria stellata*	Aditive supplements in feed. Food colorants agents in the food, poultry, and fish industries. Prevention of cardiovascular disease and cataracts. Positive response against neurodegenerative disease, infant nutrition Antioxidant properties
Zeaxanthin	*Pavlova lutheri* *Pavlova salina* *Pavlova sp* *Porphyridium cruentum*	Capacity to neutralize free radicals, act as an antioxidant and reduce inflammation
Lipids and fatty acids PUFAs: w-3 (DHA and EPA) and w-6 (ARA)	*Amphiprora hyalina* *Chlorella minutissima* *Chlorella reinhardtii* *Chlorella sp* *Coscinodiscus sp* *Nannochloropsis sp.* *Neochloris oleobundas* *Phaeodactylum tricornutum*	Regulating and controlling electron and oxygen transport, as well as membrane fluidity. Maintain the thermal adaption in the cold area. PUFAs contribute to cellular and tissue metabolism.
Proteins	*Chlorella sp.* *Crypthecodinium cohnii* *Nannochloropsis sp.* *Scenedesmus obliquus*	Human nutrition. Feed: Feeding poultry, cattle, and aquaculture animals
Amino acids	*Botrycoccus braunii* *Nannochloropsis granulate* *Porphyridium aerugineum* *Tetraselmis chuii*	Nutrient supplements for human; Animal and aquaculture feed; Cosmetics
Vitamins	*Chlamydomonas reinharditii* *Chlorella sp* *Chlorella vulgari* *Chromochloris zofingiensi* *Dunaliella tertiolecta* *Haematococcus pluvialis* *Scenedesmus vacuolatus* *Tetraselmis striata*	Vitamin K: Antioxidant and anti-aging benefits, anticarcinogenic actions . Anti-inflammatory drugs. Vitamin B: Reduces depression, strengthens the body, and protects the skin and heart. Vitamin C: Antioxidant and antiaging. Neurotransmitter, collagen, and carnitine biosynthesis. Vitamin K: antioxidant activities. Helps with eye problems, Anti-diabetic properties
Carbohydrates	*Chlorella sp.* *Dunaliella sp.* *Porphyridium purpureum*	Food or food products for animals and humans. Cosmetic products

3.3.3. Techno-economic assessment of producing algae high value-added products

Microalgae cultivated under particular stress conditions may accumulate a significant number of secondary metabolites, in addition to lipids and carbohydrates, which can be used to boost a bio-based economy (G.Markou et al., 2013). Among these metabolites, the carotenoid pigment astaxanthin is one of the most valuable algal compounds, with several applications in food, feed, cosmetics, and pharmaceuticals (Borowitzka, 1999; Richmond, 2000). Nowadays, the market value of astaxanthin ranges between $2500 to 7000 per kilogram, with a global market potential of 280 metric tons valued at $447 million in 2014. (Pérez-López et al., 2014). It is a fact that the microalgae biomass has economic potential being more and more in demand. Table 3 illustrates some of the high- added-value active compounds above-mentioned in Table 2 in the nutraceutical and pharmaceutical sector adding the market value.

Table 3. Market value for high-added-value bioactives derived from microalgal biomass. Modified from (Rehmanji et al., 2022)

Compound	Market value ($ kg-1)	Sector	References
Astaxanthina	2500-7000		Pérez-López et al., 2014
β- carotene	300 - 3000	Pharmaceutical & Nutraceutical	Hannon et al., 2010
Chlorophyll	390		Daigle et al., 2019
Omega- 3 (99% EPA/DHA)	600- 4500		Daigle et al., 2019

3.3.4. Q3: Is it conceivable to diversify in the Macaronesian region with those microalgae that have biotechnological potential, as determined by the techno-economic evaluation?

The term market diversification refers to a growth strategy in which a corporation aims to expand by introducing new goods in new markets that are unconnected to its present ones.

In this study, the behavior and knowledge of the consumer regarding the use of microalgae has been observed first, and the advantages and opportunities of the industry in Europe have been analyzed, giving positive results according to the SWOT. In addition, it has been verified that microalgae are wonderful sources of high-added-value compounds with health advantages, and they have a lot of commercial and economic potential. Proteins, pigments, polyunsaturated fatty acids, lipids, vitamins, minerals, and polysaccharides are examples of them as they are shown in Table 3. Because of their high-value biological compounds and widespread availability in aquatic systems, there has been an increase in global interest in microalgae-based products (Khanra et al., 2018)

Taiwan, the United States, Japan, China, Spain, Brazil, Israel, Myanmar, and Germany are the major producers of microalgae biomass worldwide, with a combined yearly dry biomass output of 19,000 tons and a revenue of USD 5.7 billion.

The Macaronesian area, which is bordered by saline oceans and has a hot, dry environment that is ideal for algae cultivation, is actively promoting algal biotechnology research. Although Macaronesia's economy is mostly focused on tourism, agriculture, and small companies, the algae sector's potential economic is worth promising. Despite de fact that the Macaronesia has been developing the blue biotechnology sector for several years, until now most of the biomass was obtained for food purposes. However, diversifying and expanding in the nutraceutical and pharmaceutical sector, as indicated by the European model, will bring great economic benefit to the region.

4. Conclusion

Seaweed production has expanded dramatically as a result of its popularization. Because of its various practical uses, the algal sector has become a business-oriented area in recent years. Blue biotechnology has pioneered new procedures and products for the production of vitamins, proteins, cosmetics, and health foods and more. The market for the majority of these applications is still growing, and the utilization of micro and macro algae will expand overseas into new regions such as the Macaronesia.

The present assessment has proposed a market research of the industry and its possible segmentation into new and potential sectors and its subsequent diversification in the Macaronesian market. So far, all the proposed objectives have been met and it has been possible to determine some conclusions.

Conclusion 1. According to the latest available data utilized in this study, the number of new algae production companies has been increasing steadily, demonstrating the dynamism and growth potential of the sector. In total, The European algae sector in 2020 amounted to 225 companies producing macroalgae (67%) and microalgae (33%). However, the trend goes forward for the microalgae sector since the microalgae market in Europe was 584.2 million in 2016 and is expected to reach 761 million dollars in 2022. Spirulina is one of the most worldwide cultivated microalgae. Europe continues to promote scientific evaluation work on biotechnological practices based on the active compounds of microalgae strains.

Conclusion 2. The field of marine biotechnology is associated with the possibility of sustainable environmental enhancements among the 80% of sample population, although the existence of a great lack of knowledge on the part of society regarding the current role of microalgae and their future applications must be addressed. Microalgae are becoming increasingly important as a source of biomass due to the production of secondary metabolites (for purposes other than food), particularly biochemicals, drugs, and high-value bioactive compounds, being the most promise sector, which correspond with some of the principal keywords identified by the Terminology or Wordcloud.

Conclusion 3. Nutraceuticals such as β-carotene, astaxanthin, fucoxanthin, zeaxanthin, and lutein not only enhance the diet but also assist in the prevention and treatment of illnesses and disorders, providing functional qualities. Moreover, in the last decade, the search for pharmacologically active compounds in microalgae, has grown in prominence. Furtheremore, with regards to the market value both sectors have a lot of commercial and economic potential. As society encourages a shift to "green solutions" and natural products, algae-derived like astaxanthin appears to be gaining market share.

Conclusion 4. Introducing new goods in new markets is always hazardous. In order to minimize risk, some bullet points might be considered in the context of the SWOT analysis previous to the diversification in the macaronesian market. For instance, the low economic support to the sector compared to other countries and the maturity of the sector in other markets, limited access to project finance or external factors such as the average decline in the EU economy since the Covid-19 , policy, access, resources regulation and so on. However, the advantages outweigh the downsides and despite the currently Macaronesia's economy mainly based on tourism, the microalgae sector's economic potential is promising and involves several opportunities.

Bibliography

Abt, K., Castelo-Branco, R., & Leão, P. (2021). Biosynthesis of Chlorinated Lactylates in Sphaerospermopsis sp. LEGE 00249. Journal Of Natural Products, 84(278-286). https://doi.org/10.1021/acs.jnatprod.0c00950

Araújo R, Vázquez Calderón F, Sánchez López J, Azevedo IC, Bruhn A, Fluch S, Garcia Tasende M, Ghaderiardakani F, Ilmjärv T, Laurans M, Mac Monagail M, Mangini S, Peteiro C, Rebours C, Stefansson T and Ullmann J (2021) Current Status of the Algae Production Industry in Europe: An Emerging Sector of the Blue Bioeconomy. Front. Mar. Sci. 7:626389. doi :10.3389/fmars.2020.626389

Araújo, R., Lusser , M., Sanchez Lopez, J., and Avraamides, M. (2019a). Brief or Algae Biomass Production. Luxembourg: Publications Office of the European Union.

Baker JT (1984) Seaweeds in pharmaceutical studies and applications. Hydrobiologia 116/117: 29–40

Blue Bioeconomy Forum (2019). highlights. Synthesis of the Roadmap and a Selection of Viable and Innovative Projects . Luxembourg: European Commission. Publications Office of the European Union.

Borowitzka, M. (2013). High-value products from microalgae—their development and commercialisation. Journal Of Applied Phycology, 25(3), 743-756. https://doi.org/10.1007/s10811-013-9983-9

Borowitzka, M.A. Microalgae as sources of pharmaceuticals and other biologically active compounds. J. Appl. Phycol. 1995, 7, 3–15.

Buschmann , AH, Camus, C., Infante, J., Neori , A., Israel, Á, Hernández-González, MC, et al. (2017). Seaweed production: overview of the global state of exploitation, farming and emerging research activity. Eur . J.Phycol. 52, 391–406. doi :10.1080/09670262.2017.1365175

Cai J, Lovatelli A, Aguilar-Manjarrez J, Cornish L, Dabbadie L, Desrochers A, Diffey S, Garrido Gamarro E, Geehan J, Hurtado, A., Lucente , D., Mair, G., Miao, W., Potin , P., Przybyla , C., Reantaso , M., Roubach , R., Tauati , M. & Yuan , X. 2021. Seaweeds and microalgae: an overview for unlocking their potential in global aquaculture development. FAO Fisheries and Aquaculture Circular No. 1229. Rome, FAO. https://doi.org/10.4060/cb5670en

Carmichael WW (1992) A review: Cyanobacteria secondary metabolites — the cyanotoxins. J. appl. Bact. 72: 445–459.

Centre, C. (2022). Smart specialisation and blue biotechnology in Europe.. Op.europa.eu. Retrieved 25 May 2022, from https://op.europa.eu/en/publication-detail/-/publication/c54d0861-4016-11eb-b27b-01aa75ed71a1/language-en.

Chew, K.W.; Yap, J.Y.; Show, P.L.; Suan, N.H.; Juan, J.C.; Ling, T.C.; Lee, D.-J.; Chang, J.-S. Microalgae biorefinery: High value products perspectives. Bioresour. Technol. 2017, 229, 53–62

COM. 2019. El Pacto Verde Europeo. 640 final

Deloitte Consortium (2021). Support the functioning of the EU algae markets [Webinar]. Wageningen University & Research.

Doussineau M., Haarich S., Gnamus A., Gomez J., Holstein F., Smart Specialization and Blue biotechnology in Europe, EUR 30521 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76- 27753-8, doi:10.2760/19274, JRC122818.

ECORYS (2014). Study in support of Impact Assessment work on Blue biotechnology. Revised Final Report FWC MARE/2012/06 – SC C1/2013/03. Report for DG MARE. Elaborated with MRAG and S.PRO.

European Commission (2021). The EU Blue Economy Report. 2021. Publications Office of the European Union. Luxembourg

FAO (2018). The global status of seaweed production, trade and utilization . Rome: Globefish Research Program Volume 124. Retrieved from http://www.fao.org/3/CA1121EN/ca1121en.pdf;

FAO (2020). The State of World Fisheries and Aquaculture. Sustainability in action. Rome. doi: https://doi.org/10.4060/ca9229en

Foray, D. , David, P.A. Hall, B.H. "Smart specialisation: the concept", Ch .3 in Knowledge for Growth: Prospects for science, technology and innovation, Report, EUR 24047, European Union, 2009. Also Available as K4G Policy Brief No. 9, EC (DG-Research). [Available at: http://ec.europa.eu/invest-inresearch/monitoring/knowledge_en.htm .]

Fritsche, U., Brunori , G., Chiaramonti , D., Galanakis , C., Matthews, R. and Panoutsou , C., Future transitions for the Bioeconomy towards Sustainable Development and a Climate-Neutral Economy - Foresight Scenarios for the EU bioeconomy in 2050 , Borzacchiello , MT, Stoermer, E. and Avraamides, M. editor(s), Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-28413-0, doi:10.2760/763277, JRC123532

Georgakopoulou, M., (2018). The use of microalgae in biotechnological applications. case studies 1e64. https://www.semanticscholar.org/paper/The-use-ofmicroalgae-in-biotechnological-Studies-Georgakopoulou/ 3cc75990f8be064f6a6cff776a77afd6763c91f6?p2df

Gutiérrez-del-Río, I., Brugerolle de Fraissinette, N., Castelo-Branco, R., Oliveira, F., Morais, J., & Redondo-Blanco, S. et al. (2020). Chlorosphaerolactylates A–D: Natural Lactylates of Chlorinated Fatty Acids Isolated from the Cyanobacterium Sphaerospermopsis sp. LEGE 00249. Journal Of Natural Products, 83(6), 1885-1890. https://doi.org/10.1021/acs.jnatprod.0c00072

Hamed, I., (2016). The evolution and versatility of microalgal biotechnology: a review. Compr. Rev. Food Sci. Food Saf. 15, 1104e1123. https://doi.org/10.1111/1541- 4337.12227.

Hasselström , L., Visch , W., Gröndahl , F., Nylund , GM, and Pavia, H. (2018). The impact of seaweed cultivation on ecosystem services - a case study from the west coast of Sweden. Mar. Pollut . Bull. 133, 53–64. doi : 10.1016/j.marpolbul.2018.05.00

Instituto Tecnológico de Canarias (ITC) - REBECA-CCT. [online] Available at: <https://www.itccanarias.org/web/en/activity/projects/rebeca-cct> [Accessed 2 May 2022].

Khanra, S.; Mondal, M.; Halder, G.; Tiwari, O.N.; Gayen, K.; Bhowmick, T.K. Downstream processing of microalgae for pigments, protein and carbohydrate in industrial application: A review. Food Bioprod. Process. 2018, 110, 60–84.

Kim, S.-K. Marine Pharmacognosy: Trends and Applications; CRC Press: Boca Raton, FL, USA, 2012; ISBN 978-1-4398-9229-9.

Koyande, A.K., Chew, K.W., Rambabu, K., Tao, Y., Chu, D.-T., Show, P.-L., (2019). Microalgae: a potential alternative to health supplementation for humans. Food Sci. Hum. Wellness 8, 16e24. https://doi.org/10.1016/j.fshw.2019.03.001.

Koyande, A.K., Tanzil, V., Murraly Dharan, H., Subramaniam, M., Robert, R.N., Lau, P.L., Khoiroh, I., Show, P.L., (2020). Integration of osmotic shock assisted liquid biphasic system for protein extraction from microalgae Chlorella vulgaris. Biochem. Eng. J. 157, 107532 https://doi.org/10.1016/j.bej.2020.107532

Ktari, L., Chebil Ajjabi , L., De Clerck , O., Gómez Pinchetti, J. and Rebours , C., (2021). Seaweeds as a promising resource for blue economy development in Tunisia: current state, opportunities, and challenges. Journal of Applied Phycology.

Lafarga, T., Rodríguez - Bermúdez , R., Morillas-España , A., Villaró , S., García-Vaquero, M., Morán , L., Sánchez - Zurano , A., González-López, C. and Acién -Fernández, F., (2021). Consumer knowledge and attitudes towards microalgae as food: The case of Spain. Algal Research , 54, p.102174.

Li, S., Zhao, S., Yan, S., Qiu, Y., Song, C., Li, Y., Kitamura, Y., (2019a). Food processing wastewater purification by microalgae cultivation associated with high value added compounds production d a review. Chinese J. Chem. Eng. 27, 2845e2856. https://doi.org/10.1016/j.cjche.2019.03.028.

Li, X., Li, X., Han, B., Zhao, Y., Li, T., Zhao, P., Yu, X., (2019b). Improvement in lipid production in Monoraphidium sp. QLY-1 by combining fulvic acid treatment and salinity stress. Bioresour. Technol. 294, 122179 https://doi.org/10.1016/ j.biortech.2019.122179.

Li, X., Liu, J., Chen, G., Zhang, J., Wang, C., Liu, B., (2019c). Extraction and purification of eicosapentaenoic acid and docosahexaenoic acid from microalgae: a critical review. Algal Res. 43, 101619 https://doi.org/10.1016/j.algal.2019.101619

Markou, G., Nerantzis, E. Microalgae for high-value compounds and biofuels production: a review with focus on cultivation under stress conditions, Biotechnol. Adv. 31 (8) (2013) 1532–1542, http://dx.doi.org/10.1016/j.biotechadv.2013.07.

Mimouni, V.; Ulmann, L.; Pasquet, V.; Mathieu, M.; Picot, L.; Bougaran, G.; Cadoret, J.-P.; Morant-Manceau, A.; Schoefs, B. The potential of microalgae for the production of bioactive molecules of pharmaceutical interest. Curr. Pharm. Biotechnol. (13) (2012) 2733–2750.

Morisson, A., Pattinson, M. (2020). Smart Specialization Strategy (S3). Lille: Interreg Europe Policy Learning Platform .

Morone J., Lopes G., Preto M., Vasconcelos V., Martins R. Exploitation of filamentous and picoplanktonic cyanobacteria for cosmetic applications: Potential to improve skin structure and preserve dermal matrix components. Mar. Drugs. 2020;18:486. doi: 10.3390/md18090486

Pagels, F., Vasconcelos, V., & Guedes, A. C. (2021). Carotenoids from Cyanobacteria: Biotechnological Potential and Optimization Strategies. Biomolecules, 11(5), 735. https://doi.org/10.3390/biom11050735

Pérez-López, P., González-García, S., Jeffryes, C., Agathos, S., McHugh, E., & Walsh, D. et al. (2014). Life cycle assessment of the production of the red antioxidant carotenoid astaxanthin by microalgae: from lab to pilot scale. Journal Of Cleaner Production, 64, 332-344. doi: 10.1016/j.jclepro.2013.07.011

Puri, M., Gupta, A., McKinnon, R. and Abraham, R., (2021). Marine bioactives: from energy to nutrition . Trends in Biotechnology.

Rehmanji, M., Singh, R., Nesamma, A., Khan, N., Fatma, T., Narula, A., & Jutur, P. (2022). Multifaceted applications of microalgal biomass valorization to enriched biorenewables, a review of futuristic biorefinery paradigm. Bioresource Technology Reports, 17, 100972. doi: 10.1016/j.biteb.2022.100972

Rumin , J.; Gonçalves de Oliveira Junior, R.; Berard , J.-B.; Picot, L. Improving Microalgae Research and Marketing in the European Atlantic Area: Analysis of Major Gaps and Barriers Limiting Sector Development. Mar. Drugs 2021, 19,319. https://doi.org/10.3390/md19060319

Sarkar, S., Manna, M.S., Bhowmick, T.K., Gayen, K., (2020). Priority-based multiple products from microalgae: review on techniques and strategies. Crit. Rev. Biotechnol. 40, 590e607. https://doi.org/10.1080/07388551.2020.1753649.

Sathasivam, R., Ki, J.S., (2018) A review of the biological activities of microalgal carotenoids and their potential use in healthcare and cosmetic industries. Mar. Drugs 16 (26). https://doi.org/10.3390/md16010026.

Sathasivam, R., Radhakrishnan, R., Hashem, A., Abd_Allah, E.F., (2019). Microalgae metabolites: a rich source for food and medicine. Saudi J. Biol. Sci. 26, 709e722. https://doi.org/10.1016/j.sjbs.2017.11.003

Sun, X.M., Ren, L.J., Zhao, Q.Y., Ji, X.J., Huang, H., (2019). Enhancement of lipid accumulation in microalgae by metabolic engineering. Biochim. Biophys. Acta Mol. Cell Biol. Lipids 1864, 552e566. https://doi.org/10.1016/j.bbalip.2018.10.004.

Sun, Y., Zhang, N., Zhou, J., Dong, S., Zhang, X., Guo, L., Guo, G., 2020. Distribution, contents, and types of mycosporine-like amino acids (MAAs) in marine macroalgae and a satabase for MAAs based on these characteristics. Mar. Drugs 18 (43). https://doi.org/10.3390/md18010043

The EIB Circular Economy Guide – Supporting the circular transition (2021). Publications Office of the European Union. Luxembourg

Tibbetts, S.M., Melanson, R.J., Park, K.C., Banskota, A.H., Stefanova, R., McGinn, P.J., (2015a). Nutritional evaluation of whole and lipid-extracted biomass of the microalga Scenedesmus sp. AMDD isolated in saskatchewan, Canada for animal feeds: proximate, amino acid, fatty acid, carotenoid and elemental composition. Curr. Biotechnol. 4, 530e546. https://www.ingentaconnect.com/content/ben/ cbiot/2015/00000004/00000004/art00015.

Tibbetts, S.M., Milley, J.E., Lall, S.P., (2015b). Chemical composition and nutritional properties of freshwater and marine microalgal biomass cultured in photobioreactors. J. Appl. Phycol. 27, 1109e1119. https://doi.org/10.1007/s10811-014- 0428-x

U.S. Economic Development Administration. (2020) Comprehensive Economic Development Strategy (CEDS) Content Guidelines: Recommendations for Creating an Impactful CEDS. Retrieved 3 May 2022, from https://eda.gov/ceds/content/swot-analysis.htm