MARINE BIOTECHNOLOGY: A CHALLENGING PATH TO SUSTAINABLE FOOD, FEED, ENERGY AND IMPROVED HUMAN AND ANIMAL HEALTH

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Resumo

A vida começou nos oceanos, e tanto o passado como o futuro da população humana estão intrinsecamente ligados aos recursos biológicos marinhos. A exploração responsável da vasta biodiversidade que os oceanos oferecem passa pela proteção destes e uma adequada gestão. Estudos recentes sobre a biodiversidade de organismos marinhos revelaram que o conceito da "árvore da vida" devia ser substituído por uma "teia da vida", a qual é constituída por interações múltiplas em termos de redes complexas de transferências de genes, eventos endossimbióticos e relações tróficas. A compreensão dessa complexidade e da sua história evolutiva fornece uma melhor compreensão da biologia, bioquímica e a ecologia da vida marinha que é fundamental para a efetiva exploração dos oceanos de modo a beneficiar os seres humanos como um todo de uma forma responsável. Neste trabalho, serão discutidas e apresentadas estratégias baseadas no conhecimento que estão atualmente a ser implementadas em que recursos vivos marinhos são usados como fontes inovadoras de alimento, energia e compostos bioativos para que haja um futuro mais sustentável que possa ser transmitido às gerações futuras.

Palavras-chave: Recursos marinhos; biorrefinaria, saúde humana e animal

Abstract

As life began in the oceans, the past, but also the future of the human population is intrinsically linked to marine living resources. The oceans offer a bounty of biodiversity that needs to be protected, properly managed and exploited with responsibility. Recent studies on the biodiversity of marine organisms have revealed that the tree of life is actually a web of life with multiple interactions in terms of complex networks of gene transfers, endosymbiotic events and trophic relationships. The understanding of this complexity and the evolutionary history that underlies and explains the biology, biochemistry and ecology of marine life is key to its effective exploitation to benefit human beings as a whole in a responsible manner. We will discuss knowledge-based strategies that are currently being implemented in order to use the available marine living resources as novel sources of food, feed, energy and bioactive compounds, so that a more sustainable future can be provided to future generations.

Keywords: Marine resources; biorefinery, human and animal health

1. Introduction

More than 80% of the organisms living on earth are found in the aquatic ecosystem with the marine environment containing between 250,000-270,000 different species (Reaka-Kudla, 1997; Groombridge and Jenkins, 2000). Among this enormous biodiversity, only 20% of it has been minimally characterized in terms of their genetics, biochemistry and biomedical potential (Kim et al., 2015).

Over the last few years, marine biotechnology has demonstrated that has the potential and the capacity to improve human life, where the application of biotechnological tools could develop novel and cost-effective food, feed and energy products able to improve human and animal health. Marine bioprocesses use living marine organisms as *cell factories* for the biosynthesis of these compounds. To realize the potential of marine biotechnology, it is necessary to undertake a bioprospection of biological resources with high potential to generate benefits to the economy in a sustainable way, without undermining the sustainability of the marine ecosystem.

The research groups MarBiotech of the Center for Marine Sciences (CCMAR) and Engineering and Environmental Biotechnology of the Center for Marine Environmental Research (EEB / CIMA) of the University of Algarve have joined forces to develop work in the area of microalgal biotechnology. These research groups began a bioprospection effort for studying different marine resources via isolation and cultivation of the different microalgal strains from samples collected at different locations of the Southwestern Iberian Coast under the umbrella of the ALGARED network, which is financed by the operational program EP-INTERREG VA Spain-Portugal (POCTEP). Apart from the University of Algarve, this network comprises two companies (Necton and Sea4US), one state laboratory (IPMA), two additional universities (University of Huelva and University of Cordoba), two research institutes (ICMAN, IFAPA), and Junta de Andalucia. Microalgae with interesting properties will be scaled up under different operations modes and geometries. The ultimate goal of this collaborative effort is to find different applications of microalgal bioresources that can be found in the coastal waters of the Iberia Peninsula for the production of biomass for food and feed rich in protein and high value lipids (e.g. *n*-3 polyunsaturated fatty acids), bioactive compounds, and carotenoids. The production of biofuels, such as biodiesel, bioethanol, and methane by anaerobic digestion of the residual algal fraction will also be explored (Figure 1).

2. Marine Resources Applications

Microalgal biomass production systems includes the design and operation of the biological reactors, adapted to the different trophic modes, where the microalgae growing in an environment that favors accumulation of target products and the harvest of the microalgal biomass for distinct applications.

Microalgae can be cultured under photoautotrophy, mixotrophy, photoheterotrophy and heterotrophy. Cultivation in photoautotrophy implies the use of non-organic nutrients (e.g. nitrates and phosphates) by the microalga for the photosynthesis of organic compounds through CO_2 fixation. Conversely, growth in heterotrophy requires the supplementation of the growth medium with organic carbon substrates as C and energy sources and cell growth is independent of light energy, resulting in high productivities, yields, cell concentrations and improved growth control as compared to photoautotrophic systems. This is mainly due to the supply of ready-to-use substrates that are rich in energy and the absence of growth limitations imposed by light attenuation inside the bioreactor. However, the possible contamination of culture media for the presence of organic substrates and the increasing production costs associated with the addition of organic substrates are disadvantages of this trophic mode. Heterotrophic growth is an attractive approach for the high availability of cheap carbon sources (glucose, acetate, and glycerol) commonly used by fermentation industries and the possibility of the use of wastewaters with a substantial organic load or supplemented with other cheap nutrients, that could make production from microalgae economically acceptable (Moreno-Garcia, Adjallé, Barnabé, & Raghavan, 2017). Organic substrates as diverse as monosodium glutamate wastewater, cheese whey permeate, sodium acetate, fruit peel, glucose, fructose, glycerol, etc. have been successfully used for algae growth under mixotrophic conditions (Azma, Mohamed, Mohamad, Rahim, & Ariff, 2011; D'Este, Alvarado-Morales, & Angelidaki, 2017; Daliry, Hallajisani, Roshandeh, Nouri, & Golzary, 2017; Guldhe, Ansari, Singh, & Bux, 2017; Morales-Sánchez, Martinez-Rodriguez, & Martinez, 2017; Petrushkina et al., 2017). Mixotrophic cultivation performed in both fed-batch and semi-continuous modes is a successful strategy to be used for high biomass, lipid and co-products synthesis (Chaiprapat, Sasibunyarat, Charnnok, & Cheirsilp, 2017; Daliry, Hallajisani, Roshandeh, Nouri, & Golzary, 2017; Deschênes, Boudreau, & Tremblay, 2015; Han et al., 2016; Skorupskaite, Makareviciene, & Levisauskas, 2015; Zhan, Rong, & Wang, 2017).

Other possible modes for microalgal cultivation is under a mixotrophic model, in which cells are grown in a medium containing a carbon source, but in the presence of light. This growth modality is sometimes used for growth of specific microalgae when they are scaled up industrially if the target molecules are metabolites that require photosynthesis. Moreover, some other species require even more elaborate ways of being cultivated. For example, it has been shown that the dinoflagellate *Dinophysis acuminata* needs to steal mitochondrial-plastidial complexes from a ciliate (*Myrionecta rubra*) in order to acquire transiently the capacity of carrying out photosynthesis even though is a predator of other microorganisms. In turn, *M. rubra* steals the nucleus, mitochondria and chloroplasts from a photosynthetic cryptophyte (*Geminigera cryophila*; Wisecaver and Hackett, 2010) in order to be grown and serve as live feed for *D. acuminata*. This "photoheterotrophic" lifestyle of minute predators translates the intricate and complex trophic interdependences that are found in aquatic environments, which need to be understood if one wants to cultivate these organisms.

Concerning applications of their biomass, microalgae produce lipids, proteins and carbohydrates that can be processed into both biofuels and valuable co-products with the capacity to replace fossil fuels and to supply demand for food supplements, animal feed, colorants, enzymes, and several other valuable chemicals (Moreno-Garcia et al., 2017).

The saccharides in microalgal biomass can be used to produce bioethanol or biogas via fermentation or anaerobic digestion (Chen et al., 2013; Sanchez Rizza, Sanz Smachetti, do Nascimento, Salerno, & Curatti, 2017). In the case of the *Tetraselmis* CTP4 microalga, a high yield bioethanol of 0.47 g / g was produced, reaching a very close to the theoretical maximum level (0.51 g / g) (unpublished results).

Bio-hydrogen can also be produced via biodegradation of starch extracted from microalgae. The microalgal biomass is a good and inexpensive source of protein that can be used as additives for animal and fish feeds. Some microalgae species produce several valuable bioactive compounds such as polyunsaturated fatty acids, and carotenoids such as astaxanthin (Odjadjare, Mutanda, & Olaniran, 2017).

The involvement of groups of EEB / CIMA and MarBiotech / CCMAR in the ALGARED+ network also include other laboratories located at the University of Algarve. For example, Elsa Cabrita (AQUA group) will be crucial to develop novel methods of cryopreservation for the isolated microalgae together in collaboration with IFAPA, University of Huelva and IPMA. Other groups (Leonor Cancela's, Wolfgang Link's and Dina Simes's laboratories) will be essential for the development and implementation of novel screening platforms for bioactive and extracts obtained from microalgal biomass. The objective of this network is the implementation of a strategy that promotes research and technological development in the area of microalgal biotechnology and its use in health products, cosmetics and aquaculture (Figure 2).

This project will be carried out in the Algarve / Western Andalusia cross-border area, a region heavily influenced by the Atlantic Ocean, home to ecosystems of great richness and biodiversity that can form a framework for important economic activities of great strategic importance, such as aquaculture and phycoculture. More specifically, microalgae have a high potential for innovation and may be untapped sources of wealth in the form of metabolites of pharmacological and cosmetic interest.

The ALGARED network will implement six Activities aimed at the bioprospection, isolation and valorisation of novel microalgal strains. Another goal of the network is to coordinate all these efforts across the Portuguese-Spanish border and exchange scientific personnel and students in order to push the field of microalgal biotechnology forward. This exchange will enable cross-pollination via the complementarities found among the Portuguese and Spanish partners.

3. Microalgae Biorefinery

Today, the concept of biorefinery is a prominent issue in our society that aims at the integrated exploitation of a given biological resource. This concept can be applied to microalgal biomass, so that it is fully utilized in terms of its constituent fractions, from lipids (oils) to carbohydrates and proteins. The co-production of biofuels (biodiesel, bioethanol, biofuel and biogas), protein-rich feed and extracts containing bioactive compounds with biomedical, nutraceutical and / or pharmaceutical applications is one of the scenarios to be studied.

This system could be economically sustainable and could contribute to the use of biofuels as a by-product from biomass cultivated for higher added-value products such as carotenoids, vitamins, and algal extracts with high antioxidant content for cosmetic and food products.

In this context, biofuels will also be considered as by-products resulting from the process of treating wastewaters with a high organic load. The current research at the University of Algarve, in the area of biotechnology and blue energy, intends to make use of marine bio-resources for domestic or agroindustrial effluent treatment. Wastewaters are sources rich in organic matter and nutrients that can be used in the growth of microalgae, whose biomass can be used as a source of oils for the synthesis of biofuels. This possibility of transforming the treatment of wastewaters in a potentially self-sustaining process, generating additional revenue, could lower operating costs for companies and municipalities across the Iberia Peninsula and elsewhere.

Presently, there is no biorefinery in Portugal for the production of biofuels, both bioethanol and biodiesel, to allow its incorporation into additives. If Portugal wants to fulfill its community goals, it is still dependent on the importation of (bio)fuels, which represents a significant burden on the country's economy. At present, efforts have been made to find processes that make the production of these biofuels economically viable, using an integrative approach under the concept of a biorefinery.

4. Conclusions

One of the conclusions that can be drawn right now is the urgent need for Portugal, Spain and Europe in general to support efforts related to marine biotechnology. Thus, marine biotechnology clearly stands as a key lever in the strategy of training human resources for the sustainable use of its marine resources and job creation through knowledge and innovation. The University of Algarve, through the cooperation of several national and international research groups as well as business partners, has taken important steps in this direction. The exploration of novel co-products is an important aspect of improving the economics of algal biofuels. The development of the technologies and the advances in the area of algal biofuels goes by hand in hand with the interest of the general public in the achievement of a sustainable source of clean energy and their concern over climate change and environmental remediation. The world interest in microalgae-based biorefineries is growing rapidly as shown by the increased investment from the industrial, institutional and governmental sectors, as well as by the enormous number of publications on the subject in recent years.

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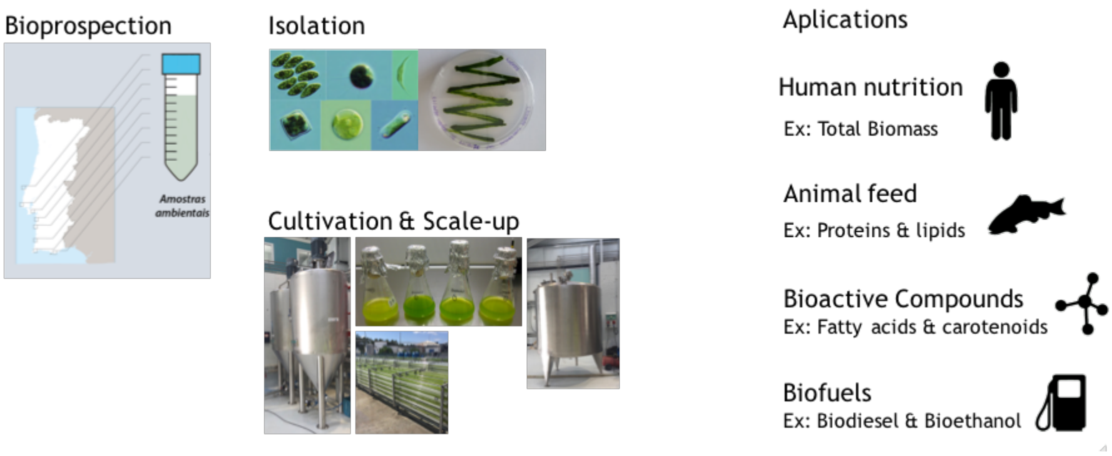

Figure 1. Different biotechnological applications from marine resources obtained by bioprospecting, isolations and cultivation of the microalgae with economical interest.

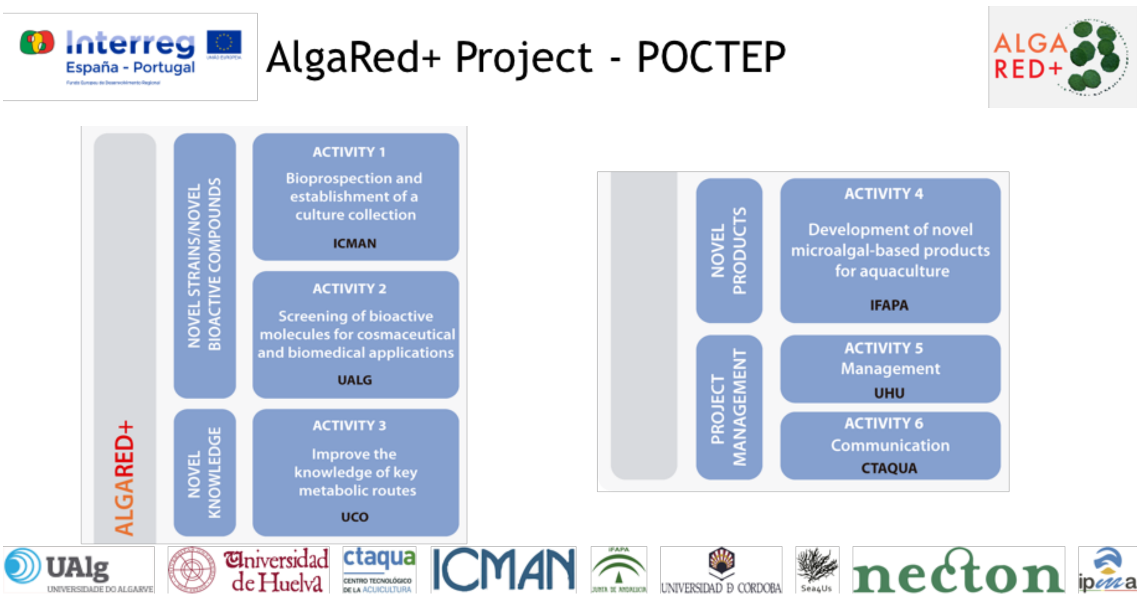

Figure 2. Algared+ Project, a network stablished between 9 institutions