Biotechnology Advances 32 (2014) 1028–1036

Contents lists available at ScienceDirect

Biotechnology Advances

journal homepage: www.elsevier.com/locate/biotechadv

Research review paper

Global unbalance in seaweed production, research effort and biotechnology markets

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ARTICLE INFO

Article history:
Received 2 December 2013
Received in revised form 9 May 2014
Accepted 14 May 2014
Available online 20 May 2014

Keywords:
Macroalgae
Patents
Aquaculture
Agriculture
Food
Bioremediation
Industry
Health
Chemical
Cosmetics

ABSTRACT

Exploitation of the world's oceans is rapidly growing as evidenced by a booming patent market of marine products including seaweed, a resource that is easily accessible without sophisticated bioprospecting technology and that has a high level of domestication globally. The investment in research effort on seaweed aquaculture has recently been identified to be the main force for the development of a biotechnology market of seaweed-derived products and is a more important driver than the capacity of seaweed production. Here, we examined seaweed patent registrations between 1980 and 2009 to assess the growth rate of seaweed biotechnology, its geographic distribution and the types of applications patented. We compare this growth with scientific investment in seaweed aquaculture and with the market of seaweed production. We found that both the seaweed patenting market and the rate of scientific publications are rapidly growing (11% and 16.8% per year respectively) since 1990. The patent market is highly geographically skewed (95% of all registrations belonging to ten countries and the top two holding 65% of the total) compared to the distribution of scientific output among countries (60% of all scientific publications belonging to ten countries and the top two countries holding a 21%), but more homogeneously distributed than the production market (with a 99.8% belonging to the top ten countries, and a 71% to the top two). Food industry was the dominant application for both the patent registrations (37.7%) and the scientific publications (21%) followed in both cases by agriculture and aquaculture applications. This result is consistent with the seaweed taxa most represented. Kelp, which was the target taxa for 47% of the patent registrations, is a traditional ingredient in Asian food and *Gracilaria* and *Ulva*, which were the focus of 15% and 13% of the scientific publications respectively, that are also used in more sophisticated applications such as cosmetics, chemical industry or bioremediation. Our analyses indicate a recent interest of non-seaweed producing countries to play a part in the seaweed patenting market focusing on more sophisticated products, while developing countries still have a limited share in this booming market. We suggest that this trend could be reverted by promoting partnerships for R and D to connect on-going efforts in aquaculture production with the emerging opportunities for new biotech applications of seaweed products.

Contents

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http://dx.doi.org/10.1016/j.biotechadv.2014.05.002
0734-9750/

Introduction

Domestication of marine biodiversity, albeit a recent phenomenon, is accelerating through new developments in biology and biotechnology (Duarte et al., 2007) as well as a diversification of the use of biological resources in increasingly sophisticated products (Arrieta et al., 2010) and biotechnological applications (Arico and Salpin, 2005). Whereas the rate of discovery of new marine species is still slow (0.93% per year) (Arrieta et al., 2010) and the number of domesticated marine species is growing at about 3% per year (Duarte et al., 2007), the number of natural marine products of commercial interest (e.g. cosmetics, industrial enzymes or genes derived from marine organisms) and marine gene patents is growing rapidly at a rate of 4% and 12% per year respectively (Arrieta et al., 2010), and marine aquaculture production grows at 7% per year (Duarte et al., 2009). Collectively, the steep growth in the use of marine biological resources represents a fundamental change in the way humans relate to the oceans (Duarte et al., 2007).

Whereas eukaryotes dominate the growth in marine natural products and domesticated species (Arrieta et al., 2010), most of the gene patents derive from prokaryote genes (Arrieta et al., 2010; Leary et al., 2009). The exploitation of these marine resources is not equally accessible to all, since prospecting the microbial realm for biotechnological applications requires highly sophisticated technology and financial investment, which favours access of wealthier countries (Arnaud-Haond et al., 2011; Leary et al., 2009). Patenting of resources is also costly, leading to a hugely skewed distribution of patent claims, with ten highly developed nations owning 90% of all marine gene patents and a majority of undeveloped nations not participating in this development (Arnaud-Haond et al., 2011). In addition, a legal gap affects the use of biological resources in the Areas Beyond National Jurisdiction, which the Convention of Biological Diversity (CBD) fails to regulate (Arico and Salpin, 2005; Arnaud-Haond et al., 2011; Leary et al., 2009; Sheridan, 2005). The growth of aquaculture has also been hindered by the high environmental impacts of some forms of aquaculture, particularly those of fish and shrimp (Primavera, 2006), which have lead to regulatory frameworks that restrict the areas where aquaculture can be deployed. Hence, the growth in the use of marine biodiversity as a source of food and bio-resources has met technological, legal and regulatory constraints that may affect further development of this industry.

In this context, the exploitation of marine macroalgae (hereafter referred to as seaweed) provides a solution to these problems, because seaweed farms are located in coastal waters and therefore accessible and involve low-cost technology (Briggs and Funge-Smith, 1993; Troell et al., 2003) and because seaweeds have simple life cycles that render their domestication easy. In addition, seaweed farms bring benefits, rather than impacts, to the environment (Duarte et al., 2009; Troell et al., 2003). The expansion and integration of seaweed in marine aquaculture production has been proposed to be a necessary pillar of the capacity of aquaculture to meet the growing global food demand (Beveridge et al., 1997; Duarte et al., 2009). Indeed, seaweed aquaculture is a rapidly growing component of marine aquaculture, with about 0.17% of all named marine seaweed having been cultured to date (Duarte et al., 2007) and a growth rate of global marine seaweed production at 7.5% per year (Duarte et al., 2009). Hence, seaweed production provides important opportunities for developing countries, and is accordingly growing rapidly in Africa, South America and SE Asia (Wikfors and Ohno, 2001). In parallel, the range of sectors demanding products of seaweed farming has widened, from an initial focus to direct food supply to humans, to include bio-energy (Kraan, 2013), cosmetics (Kijjoa and Pichan, 2004), biomedical applications (Smit, 2004) and formulation of feeds for aquaculture animals (Carrillo Dominguez et al., 2002).

The combined effect of rapidly increasing domestication and production with increasing demand for seaweed products is likely to be acting to promote innovation in seaweed biotechnology. However, a comparison of patenting and seaweed aquaculture among countries demonstrated that, while seaweed aquaculture was shown to play a role, it only led to innovation and patenting of new products when accompanied by substantial scientific effort (Mazarrasa et al., 2013). Naturally, the demand for seaweed products has generated the impetus for increased knowledge to resolve bottlenecks in the development of seaweed aquaculture, as for example the selection of suitable environments for growth; engineering of the seashore for farming; protection of crops from pests and physical or biotic impacts; and proper transplantation and harvesting procedures (Buschmann et al., 1995). Research on the biology, ecology, biochemistry and the life cycle of seaweed species, which can be relatively complex, helped unlock the capacity to bring some seaweed species, such as Laminaria and Undaria, into culture (Wikfors and Ohno, 2001).

We therefore expect that the growth and distribution of seaweed-related patents will vary among countries depending on their investment in research, their access to sophisticated technologies and their tradition of seaweed aquaculture. It is likely that these differences will also be reflected in the distribution of patent categories among countries. Although patenting does not necessarily lead to an effective use of a resource, the number of patent registrations provides an indication of the potential for innovation and economical benefit being derived from a resource (Arnaud-Haond et al., 2011) and the distribution of technological effort among countries.

Here, we evaluate the growth of seaweed biotechnology by examining the patents for seaweed aquaculture and seaweed-derived products registered between 1980 and 2009, and compare it with the research effort invested based on the scientific publications related to seaweed aquaculture produced between 1970 and 2011. We classified the patents and scientific peer-reviewed articles according to their geographic origin, the applications of the products being patented or published and the genus and species of seaweed being exploited, and we examined growth and distribution across time among these categories.

Methods

Patent data compilation

We extracted information on seaweed patents registered during the period 1980–2009 from the Derwent Innovations Index that includes information from 41 patent issuing authorities around the world, by conducting a boolean search via the Web of Knowledge, using the key words [macroalga* or seaweed* or chlorophy* or rhodophy* or phaeophy* or kelp or fucus* or fucoid* or ulva* or gracillaria or enteromorpha or laminaria or caulerpa or ascophyllum or chondrus or codium or sargassum or porphyra or undaria].

This search identified a total of 9021 patents on seaweeds. We subsampled random sets of 100 patents from the resulting database to estimate the distribution of patents among categories describing the patents (geographic origin, applications of the products patented, and the identity of the seaweeds included) as well as to quantify the