Biotechnological Applications of Seaweeds

Elhafid Nabti
Editor

Biotechnology in Agriculture, Industry and Medicine

NOVA

BIOTECHNOLOGY IN AGRICULTURE, INDUSTRY AND MEDICINE

BIOTECHNOLOGICAL APPLICATIONS OF SEAWEEDS

ELHAFID NABTI
EDITOR

nova
science publishers
New York

Library of Congress Cataloging-in-Publication Data

ISBN: 978-1-53610-968-9

Published by Nova Science Publishers, Inc. † New York

BIOTECHNOLOGY IN AGRICULTURE, INDUSTRY AND MEDICINE

BIOTECHNOLOGICAL APPLICATIONS OF SEAWEEDS

BIOTECHNOLOGY IN AGRICULTURE, INDUSTRY AND MEDICINE

Additional books in this series can be found on Nova's website under the Series tab.

Additional e-books in this series can be found on Nova's website under the eBooks tab.

FOREWORD

One of the key issues of our times, when big global challenges need to be solved for securing and improving the climate and a good future for mankind, is the sustainable use of abundant natural biological resources in a knowledge-based efficient manner. In addition to the optimization of agricultural practices with less applications of chemicals and the removal and avoidance of environmental pollution, the preservation of major ecosystems and balancing out ecological constraints and biotechnological developments are important tasks. The possibility to create new chances for income to people in especially rural areas is another important aspect and motivation to focus in on the better utilization of quite abundant natural resources. Since long, the seaweeds in coastal regions around the world are being used as fertilizer for agriculture. As can be learned in this book, the up-to-date knowledge about the potentials of seaweeds/macroalgae is enormous and a wide diversity of applications are available.

In the book "Biotechnological application of seaweeds", edited by Dr. Hafid Nabti, University of Béjaia, a wide scope of issues related to seaweed ecology, biodiversity and application is presented. The introductory chapter of S. Satheesh et al. on "Ecological significance of seaweeds in coastal ecosystems" presents an overview about the diversity of seaweeds and the diversity in each major group. Getting in on functional aspects, the occurrence and importance of seaweed-associated microbes for the morphology and nutrition of macro-algae is pointed out. In particular, the production of specific biologically active compounds, which protect the seaweed host, has for example led to the identification of biologic antifouling compounds. In coastal areas, seaweeds / macro-algae themselves are the living habitats for a huge diversity of invertebrates and thus for faunal life. In addition, the diversity and health of the macro-algal populations are valid bio-indicators for habitat quality. It is important to realize in time, that an extensive use of seaweeds for diverse important applications constitutes a serious threat to natural seaweed biodiversity. Therefore, there is urgent need for further developments to establish aquaculture systems for economically important seaweeds.

Due to the major life strategy of seaweeds/macro-algae to filter the seawater, macro-algae take up not only essential nutrients from the water body but also contaminants originating from agricultural run-off, like herbicides and pesticides but also nitrogen and phosphate fertilizers. This contributes to a large part to counteract eutrophication and contamination of coastal water. The important aspect of phyto-remediation of seaweeds is detailed in the chapter of Mourad Baghour. In addition to the removal of organic contaminants, the uptake of heavy metals is another important function of macro-algae to protect aquatic ecosystems. The use of macro-algae as bio-indicators for monitoring of environmental quality is also outlined in this chapter as well as different mechanisms of metal adsorption and accumulation and the degradation of organic pollutants.

A major aspect of the application of seaweeds is certainly to improve agriculture in several ways. In the chapter "Impact of seaweeds in agriculture" of D. Juvaraj and P. K. Gayathri, the reasons for many beneficial actions of seaweeds on plant development are outlined in detail. Seaweeds and seaweed-based products contain considerable amounts of macro- and micronutrients as well as plant hormones like auxins, gibberellines and cytokinins which support seed germination of plants but also growth and biomass development of crop plants. Due to their challenging life in salt water, macro-algae have developed an array for substances to prevent them from microbial attack as well as devastating grazing animals. Thus, macro-algae are themselves an effective and eco-friendly pesticide ready to be applied in different forms like seaweeds extracts, compost or mulch different commercial seaweed products. In addition, all seaweeds have developed excellent ways to cope with salt stress using so-called osmolytic substances like betaines or specific amino acids and sugars, which protect them from the inhibitory effect of high salt concentrations and a lack of available water in periods of dryness. Liquid seaweed concentrate is used as either soil conditioner due to their high content of polymeric carbon compounds or as foliar fertilizer. The different ways of plant growth promotion, like as soil conditioner, biofertilizer, growth stimulator or in pest and disease management are described in detail in the chapter of Juvaraj and Gayathri. The application of seaweeds to cope with salinity effects on crop plants is presented in the chapter of Cristina Cruz and

Ajit Varma. Experiments with the brown seaweed Ascophyllum nodosum are presented, which is used for centuries as biofertilizer and/or biostimulant to promote plant growth and improve its tolerance against biotic and abiotic stress, like increased salinity. The fertilization of salt stressed tomato plants with extracts of A. nodosum improves the salt tolerance, in particular the stabilization of $Na+/K+$ balance in leafs, and the uptake of Zn.

Last but not least a detailed overview about the manifold "Therapeutic and pharmaceutical applications of seaweeds" are contributed by Rai Abdelwahab. Due to their extremely high metabolic diversity, marine seaweeds have an outstanding position as source of pharmaceutical compounds which are used in medicine for treating e.g., diverse cancer forms, heart and lung diseases, asthma, eczema, arteriosclerosis, renal disorders, gall stones, stomach ailments, scabies, psoriasis and so on. Among the most important substance classes with pharmaceutic activity are alkaloids, terpenoids, sterols, phenolic compounds, but also halogenated alkans and alkens, hydroquinons, polysaccharides, glycoproteins and fatty acids. In addition, seaweed extracts provide a big reservoir of antibiotics against severely pathogenic Gram-negative and Gram-positive bacteria, different viruses and pathogenic fungi. Since oxidative stress is involved in various forms of pathophysiology, the wide range of antioxidant activity of an array of compounds of seaweeds have a broad scope of beneficial effects.

Thus, this book presents a timely compendium of major aspects of all aspects around seaweeds/macroalgae and presents much valid information about mechanistic aspects of the multiple beneficial aspects of seaweeds. The interested reader also gets the chance for further reading using the multiple lists of original publications in this highly relevant research field.

München/ Neuherberg, 27.11.2016

Anton Hartmann

Helmholtz Zentrum München,
Abteilung Mikroben-Pflanzen-Interaktionen
und Ludwig-Maximilians-Universität München

CONTENTS

In: Biotechnological Applications of Seaweeds ISBN: 978-1-53610-968-9
Editor: Elhafid Nabti

Chapter 1

AN INTRODUCTION TO THE ECOLOGICAL SIGNIFICANCE OF SEAWEEDS ON COASTAL ECOSYSTEMS

S. Satheesh**[*]**, ***A. A. Siddik,***
M. A. Ba-Akdah and A. A. Al-Sofyani
Department of Marine Biology, Faculty of Marine Sciences,
King Abdulaziz University, Jeddah, Saudi Arabia

ABSTRACT

Seaweeds (macroalgae) play a key role in coastal ecosystems by providing space for marine microorganisms and higher organisms, as a nursery ground for fishes and maintain the overall biodiversity structure. Seaweeds are also considered as major primary producers in the reef ecosystems and form an important part of trophic structure. For environmental monitoring programme, seaweeds are used as good bioindicators to assess the pollutant level in marine waters. Besides, many seaweed species have phytochemicals and attain economic significance. This chapter describes the ecological significance of seaweed communities in coastal ecosystems and discusses the need for conservation of seaweed beds.

[*]Corresponding Author E-mail: ssathianeson@kau.edu.sa, satheesh_s2005@yahoo.co.in

Keywords: seaweeds, ecosystem engineer, bioindicator, bioactive metabolites, coastal ecosystems

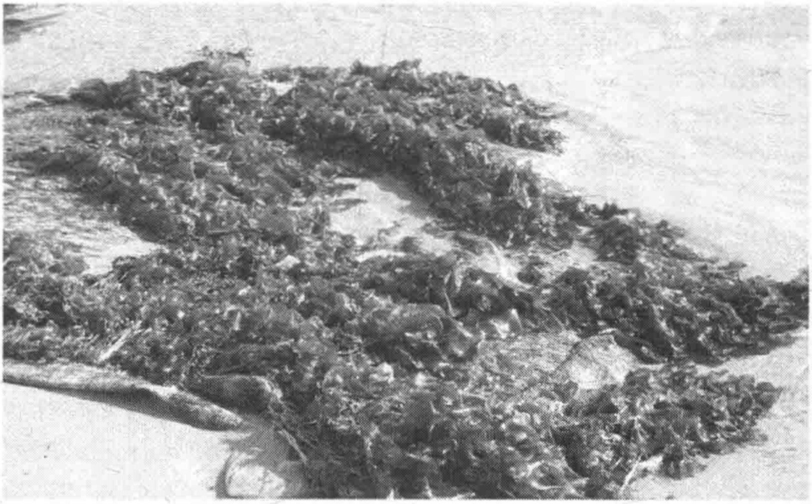
INTRODUCTION

Seaweeds or macroalgae are the abundant space occupiers and primary producers in the marine ecosystems with great ecological and economic significance (Egan et al. 2013; Ba-akdah et al. 2005). Seaweeds grow abundantly along the coastline, particularly on rocky shore regions. Generally, they are abundant in the intertidal region due to the availability of the substratum (Figure 1).

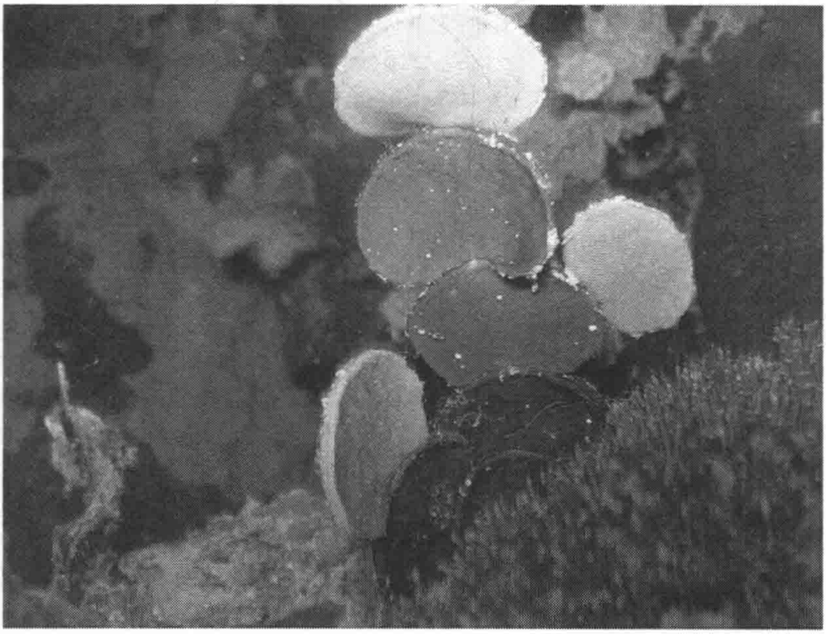
Seaweeds are classified into three main groups based on the presence of photosynthetic pigments, storage of food products and fine structure of the cells (Dhargalkar and Kavlekar, 2004). The broad seaweed groups are Chlorophyceae (green algae), Phaeophyceae (brown algae) and Rhodophyceae (red algae). The green algae contain photosynthetic pigments such as chlorophyll *a, b* and carotenoids. In brown algae, the photosynthetic pigments include chlorophyll *a, c* and fucoxanthin. The carotenoid fucoxanthin and others give yellow to deep brown colour to the brown algae (Dhargalkar and Kavlekar, 2004). The red seaweeds have chlorophyll *a*, phycobilins and carotenoids as photosynthetic pigments. The colouration of red seaweeds is due to the presence of phycobilins which include red coloured phycoerythrin and blue coloured phycocyanin (Dhargalkar and Kavlekar, 2004).

There are considerable variations among the species which are classified under these three groups, particularly on ecological and physiological aspects (Toth and Pavia, 2007). For example, brown seaweeds are normally larger in size and some are commonly called as kelp (McHugh, 2003). Kelps (large seaweeds of the order Laminariales) are abundant throughout the temperate seas (Steneck et al. 2002) and provide an extensive ecosystem for many marine communities. Kelp forests usually support high primary productivity and enhanced secondary productivity in coastal ecosystems (Smale et al. 2013). Red and green macroalgae are small in size with the size ranging from a few centimeters to a meter (McHugh, 2003). Macroalgae lack specialized tissues such as root system and vascular structures which are present in plants (Graham and Wilcox, 1999). It has been estimated that about 200 species of seaweeds are exploited for valuable economically important products such as aging, agars, carrageenans and food products (Zemke-White and Ohno, 1999).

Seaweed production along the coastal regions of the world, particularly in Asian countries increases in the recent past due to the economic significance.



A



B

Figure 1. Distribution of seaweeds on coastal ecosystems. A) Growth of *Ulva* on a rocky shore B) *Halimeda* on a reef.

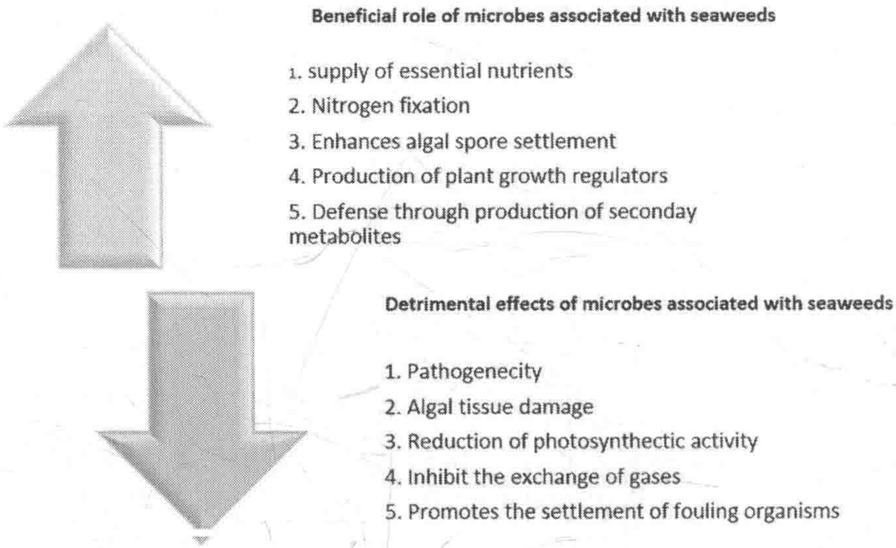


Figure 2. Possible advantages and disadvantages of microbes associated with seaweeds in coastal ecosystems.

MACROALGAE-MICROBE ASSOCIATION

All the living and non-living surfaces in the marine waters are colonized by the microbial population from the surrounding environment. The surface of marine invertebrates and macroalgae is also no exception as they are colonized by microorganisms (Egan et al. 2013; Satheesh et al. 2016). Seaweeds provide a microhabitat for many microorganisms with densities varied between 10^2 to 10^7 cells cm^{-2} depending on macroalgal species, sampling season and region (Armstrong et al. 2000; Bengtsson et al. 2010). The macroalga-microbe relationship is attributed for many purposes (Figure 2). The associated microorganisms, particularly the bacterial community provide protection and maintain the health of host alga (Egan et al. 2013). Many studies have indicated that bacterial communities associated with macroalgae are necessary for the normal morphological development of algal host (Matsuo et al. 2003; Singh et al. 2011). In addition, microbial communities also supply essential nutrients, mainly fixed nitrogen to the macroalgal host (Philips and Zeman, 1990). It has been noted that the nitrogen fixation activity of associated bacteria significantly influences the growth of seaweeds particularly red and green seaweeds (Chisholm et al. 1996; Singh et al. 2011; Singh and Reddy, 2014).

Research studies also indicated that bacterial communities associated with macroalgae enhance the settlement of zoospores in many algal species (Dillon et al. 1989; Joint et al. 2000; Shin, 2008). Another important role of microorganisms associated with the macroalgae is the production of plant growth regulators (Sing and Reddy, 2014). These plant growth regulators may affect the growth of the macroalgae as evidenced from previous studies (Spoerner et al. 2012). On the other hand, the microbial communities associated with seaweeds produce biologically active compounds (mainly for antifouling) and these compounds ensure the protection of the host (Goecke et al. 2010; Satheesh et al. 2016).However, some studies also revealed the negative aspect of microbes associated with macroalgae. For instance, the microbial films on macroalgae may reduce the incident light, inhibit the exchange of gases and hinder photosynthesis (Wahl, 1989; 2008). Also, the microbial communities associated with the algal surface may be a source of disease-causing pathogen to the host (Largo et al. 1995). While microbe-macroalga association provides an opportunity to explore some useful compounds, the functional role of this association in coastal ecosystem processes needs to be studied in detail.

SEAWEEDS AS A HABITAT FOR INVERTEBRATES

Seaweeds are reported to provide nutrition and shelter to diverse groups of invertebrates (Wikstrom and Kautsky, 2004; Cacabelos et al. 2010; Ba-akdah et al. 2015). Most importantly, the macroalgae increase the amount of space for attachment of sessile organisms; provide protection from environmental conditions such as wave action, desiccation and heat (Viejo, 1999). Studies from various coastal regions suggest that the invertebrates associated with the seaweeds are taxonomically and morphologically diverse, and exhibit a wide range of trophic habits. For example, these associated organisms may consist of filter feeders (Caine, 1977), detritus feeders (Zimmerman et al., 1979), predators which eat other epifauna (Roland, 1978) and herbivores which eat epiphytic algae or the host plant (Brawley and Feil, 1987; Duffey, 1990; Viejo, 1999).

Marine invertebrates such as polychaetes, amphipods, isopods and gastropods are commonly observed on the surface of seaweeds and these organisms may form an important food source for juvenile fishes, which are also abundant in seaweed habitats (Bray and Ebeling, 1975; Jones, 1988). In general, by acting as refugia for marine invertebrates, seaweeds contribute largely to the maintenance of biodiversity and coastal ecosystem functioning. For example, diversity and abundance of organisms are high in those coastal habitats which possess vegetation than unvegetated regions (Steneck et al. 2002).

SEAWEEDS AS A BIOINDICATOR FOR ENVIRONMENTAL MONITORING

The coastal environments throughout the world are experiencing constant exposure to pollutants from anthropogenic sources. Many marine sessile organisms are considered as bioindicators for environmental quality assessment of the marine waters. A bioindicator is an organism which gives overall information on the presence or absence of a pollutant and the concentration. Seaweeds can be used as good indicators to monitor the environmental changes due to anthropogenic and natural stressors because of their sessile mode of life (attached to a substratum) and abundance in most of the rocky coastal regions of the world (Philips, 1980). Several previous investigations revealed the effectiveness of seaweeds as bioindicators of heavy metal pollution in the marine environment (Villares et al. 2001; Chaudhuri et al. 2007; Juanes et al. 2008) as they have the ability to accumulate the metals (Haroon et al. 1995).The thallus of the seaweeds absorbs the nutrients and other materials from the surrounding environment. Hence, the toxic elements present in the water will also get accumulated in seaweeds.

ROLE OF SEAWEEDS IN NUTRIENT RECYCLING IN COASTAL ECOSYSTEMS

The seaweeds are a source of nutrient recycling and act as a base for food chains in oligotrophic coastal waters (Blanche 1992). This is due to the fact that seaweeds have photosynthetic activities in which they absorb carbon dioxide and release oxygen. According to Ryther (1963), global benthic macroalgae production was estimated at about 10% of phytoplankton. Seaweeds support other biosystems such as reefs, seagrass meadows, and mangroves by exporting good amount of particulate organic matters carried out by currents and tides (Hurd et al. 2014). Further, seaweeds are reported to be involved in the biogeochemical cycling of nutrients, particularly, nitrogen and phosphorus (Atkinson and Smith, 1983; Lapointe et al. 1992). Seaweeds also play an important role in maintaining water quality by removing the nutrients and organic materials, particularly in the eutrophicated regions (Okuda, 2008).

Macroalgal Chemical Defense against Predators

The majority of the seaweeds produce secondary metabolites (Amsler 2008), also known as allelochemicals as a defense mechanism against herbivores. These compounds are toxic to microorganisms (Culioli et al. 2008) and invertebrates (Davis et al. 2005). The production of these biologically active compounds is due to the competition and predation (Hay 1996). Competition mainly occurs between macroalgal communities owing to the availability of limited space for growth and distribution. Macroalgae are constantly subjected to attack from various herbivores that feed on algae (Rothausler et al. 2005). Marine herbivores also play important roles in structuring and functioning of coastal ecosystems (McCarty and Sotka, 2013). For example, the distribution of macroalgal communities of coastal ecosystems mainly depends on the defense mechanism of the algae (Van Alstyne, 1989, Hay 1997).Many studies have demonstrated the ability of macroalgal compounds for preventing fouling and grazing by herbivores (Paul et al. 2001; Amsler and Fairhead, 2005; Pansch et al. 2009; Thabard et al. 2011). Macroalgae that exposed to higher herbivory and predation are reported to produce more biologically active compounds. This view is supported by the ability of the seaweeds to induce chemical defenses in response to the attack of herbivores (Flothe et al. 2014). The secondary metabolites produced by the seaweeds in response to competition and predation had biotechnological applications as they could be used as a potential lead for the development of biopharmaceuticals, nutraceuticals, and antifouling compounds.

THREATS TO SEAWEED BIODIVERSITY

Coastal ecosystems are considered as the most vulnerable environment to anthropogenic and climate change induced impacts. Mainly, human activities along the coastal region have increased in recent times that produced deleterious effects on the marine biota (McIntyre, 1977). Seaweed beds along with other coastal systems provide important services to the ecosystem and any change in these systems will affect the human societies (Harley et al. 2012). Seaweeds are under threat in developing countries, where they are being disturbed by a variety of human activities. Mainly, changes in the coastal regions due to reclamation or construction activities resulted in serious deleterious effects on seaweed habitats (Okuda, 2008). Also, changes in global temperature and ocean acidification process are causing major shifts in biological systems (Harley et al. 2012). Seaweed growth, recruitment, survival, and reproduction are influenced by different environmental parameters such as temperature, salinity and nutrient concentration (Luning and Neushul, 1978; Lobban and Harrison, 1997; Steen 2004). Increasing concern about the destruction of seaweed beds and changes to the habitats warrant observational and experimental studies on macroalgal communities for better management of natural marine systems.

CONCLUSION

Seaweeds are an important ecosystem engineer which provides space for many marine organisms and structuring the coastal biodiversity. The functional role of seaweeds in coastal ecosystems is multifold from nutrient recycling to harbour micro- and macro-organisms. While, seaweeds exploited for many commercial purposes, including biologically active materials, a holistic approach is needed for conservation of this precious coastal system. Aquaculture of economically important seaweeds is progressing mainly for the food market and biofuel production (Neori, 2009; Borines et al. 2011; Egan et al. 2013). In addition, secondary metabolites produced by the seaweeds could be utilized as a potential source for pharmacological compounds and antifouling compounds. The ecological and economic significance of seaweeds emphasize the need for adequate conservation and management strategies.