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Review paper

An Overview of the Bioactive Compounds and Bioremediation Potential of Brown Algae

Fahim Al-Rashid [a], Piyush Khanna [b,] *

[a] *College of Agricultural and Marine Sciences, Sultan Qaboos University, PO Box 34, Al-khod, Sultanate of Oman*
[b] *Centre for Postgraduate Studies, Department of Applied Sciences, Middle East College, Muscat, Sultanate of Oman*

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ABSTRACT

The ability of heavy metals bioaccumulation to cause toxicity in biological systems—human, animals, microorganisms and plant is an important issue for environmental health and safety. The exploitation of different plant materials for the biosynthesis of nanoparticles is considered a green technology because it does not involve any harmful chemicals. This review highlights better understanding of the problems associated with the toxicity of heavy metals to the contaminated ecosystems and their viable, sustainable and eco-friendly bioremediation technologies, especially the mechanisms of phytoremediation of heavy metals. However, the challenges (biosafety assessment and genetic pollution) involved in adopting the new initiatives for cleaning-up the heavy metals-contaminated ecosystems from both ecological and greener point of view must not be ignored.

1. Introduction

Marine algae contain a diverse range of different species, which are generally classified into two groups, namely, microalgae and macroalgae. Phytoplankton a microalgae species survive suspended in the water column, whereas macroalgae (commonly known as seaweed) are plant-like organisms that range from a few centimeters up to several meters in length. For example, the massive kelp grows up from the seafloor to form vast underwater forests. Seaweeds have adapted to live in a variety of habitats and are capable of receiving sufficient light to promote photosynthesis ranging from small tidal rock pools close to shore or living several kilometers offshore in seawater depths. Algae are generally classified into three groups based on the algal body or thallus pigmentation. The color groups are brown algae (phaeophytes), green algae (chlorophytes), and red algae (rhodophytes) (El-Rafie et al. 2013). In water depths where light levels are chiefly low, brown and red algae are found whereas

* **Corresponding author**: Piyush Khanna, **E-mail**: p-khanna@mec.edu.om

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green algae are found in both marine and freshwater environments. Coastal communities have consumed seaweed as a nutritional supplement to their diets and as an ingredient in medicinal remedies for many years. Even today, seaweed is a staple food source and medicinal remedy in daily use throughout South-East Asia and Japan.

Several studies have revealed that seaweeds are a rich source of biologically active compounds such as carbohydrates, carotenoids, polysaccharides, proteins, vitamins, and numerous secondary metabolites. There are varied bioactive compounds present in seaweeds with potent medicinal properties that can be used in conventional treatments and alternative therapies (Smit, 2004). Studies have also shown seaweed extracts can have both anti-inflammatory and inhibitory properties that can be used to treat various medical conditions and suppress some forms of cancer (Liu et al., 2012). In addition, seaweeds also capable of accumulating heavy metals (Mohamed et al., 2012) and therefore the secondary metabolites of several kinds of seaweed have anti-biological fouling properties (Sethi, 2011). Furthermore, recent studies have reported the biological reduction of metal ions in aqueous based seaweed solutions (Chanda et al., 2010).

Many macroalgae are able to accumulate high levels of trace metals, which are sometimes larger than those found in water samples from the same site and also have the ability to produce phytochemicals of potential interest (Wada et al., 2011). Bioremediation is one of the most viable options for remediating water contaminated by organic and inorganic compounds considered detrimental to environmental health. The remediation is the option offers green technology solution to the problem of hydrocarbon and heavy metals contamination. The lower concentration of contaminants deals with bioremediation where the cleanup by physical or chemical methods would not be viable. This process offers a cost effective remediation technique, compared to other remediation methods, because it is a natural process and does not usually produce toxic by-products. It also provides a permanent solution as a result of complete mineralization of the contaminants in the environment. Biosynthesis of different metallic nanoparticles may be triggered by several compounds present in marine algae (Namvar et al., 2012). The physiological properties of seaweeds and their active principles promote aquaculture for the productive and low cost cleanup of many polluted areas. The unique marine habitat infested with diverse seaweeds is Southwest coast of India. Hence, this review explores different metal and metal oxide nanoparticles biosynthesized from marine bio resources and their application for bioremediation.

2. Seaweeds and their Biomedical Importance

The utilization of marine plants for medicinal purposes originate, from the Chinese "Material Medica" of Shen-Nung 2007 BC. The role of algae and plankton as medicine in ancient time has been described in detail by Ananthi et al., (2012) and Schwimmer and Schwimmer (1955). Marine algae include diverse species and so they form the abundant source of varied nature of bioactive compounds having medicinal properties (Table 1).

Table 1 Brown algae (sea weeds) and their medicinal value

Species	Compound/ Activity	Source
Ascophyllum nodosum	Active substance is fucan, a sulfated polysaccharide inhibits vascular muscle cell proliferation	Logesrt et al. (1977)
Sargassum polycystnum	Inhibits tumour in mice	Cui et al. (1997)
Sargassum vulgare	Effective in increasing serum lipolytic activity	Logesrt et al. (1977)
Padina pavonica	Antibacterial activity	Nadal (2000)
Turbinaria ornata	Shows anticoagulative action	Cui et al. (1997)
Laminaria hyperborean	Fronds contains Laminarin	Hoppe (1976)
Sargassum muticum	It cures goiter and renal disorders	Nadal (2000)
Dictyota dichotoma	Iodo amino compounds	Hoppe (1976)
Turbinaria decurrens	Having antilipemic properties	Chapman (1990)
Sargassum confusm	Sargaline-has been reported to reduce the blood	Nadal (2000)

	sugar level	
L.saccharina	Hypoglycemic substance was found to lower blood sugar	Park et al. (1999)
Laurencia subopposita	Laurinterol-antibaterial against Staphylococcus	Irie et al. (1970)
Chondria littoralis	Chondriamide-a new indole amide isolated is active against Nippostringylus brasiliensis	Nadal et al. (1963)
C. armata	Domoic acid	Park et al. (1999)
Ascophyllum sps	Algin capsules can be used to endose substances that must be liberated intestinally	Chapman (1990)
D. pfaffii	Diterpene-Anti-retroviral, Cytotoxic	Pereir et al. (2004)
Laminaria hyperborean	Anticoagulant activity	Starr,et al. (2004)

3. Nanoparticles Biosynthesised from Seaweeds

Nanotechnology is emerging as a rapidly growing field with its application in Science and Technology for the purpose of manufacturing new materials at the nanoscale level (Schwimmer and Schwimmer, 1995). As selection of size and shape of nanoparticles provides an efficient control over many of the physical and chemical properties and their potential application in optoelectronics, recording media, sensing devices, catalysis and medicine, is an important area of research in the synthesis and characterization of nanoparticles (Dhamotharan et al., 2012).

Among the biological systems, the marine sources are greatly deserved for the synthesis of different nanoparticles because of their diversity richness and high tolerance under ambient conditions of temperature, pressure and acidity (Kim et al., 2007). Marine macroalgae (seaweeds) have a number of distinctive phytochemicals such as heteropolysaccharides, alkaloids, steroids, phenols, saponins and flavonoids (Zaneveld, 1995). Studies have assured that biomolecules like protein, phenols, flavonoids and some phytochemicals have the ability to reduce the ions to the nanosize and also play an important role in the capping of the nanoparticles for its stability.

4. Therapeutic Potential of Different Nanoparticles Biosynthesised from Seaweeds

Algae are otherwise called bionanofactories because they synthesized nanoparticles with high stability, are easy to handle, and eliminate cell maintenance. Algae are the naturally occurring plant, which consists of phytochemicals that are involved in the production of metallic nanoparticles. Recently, gold nanoparticle synthesized using the extract of algae such as *Sargassum wightii* (Esmaeili and Darvish, 2014), *Turbinaria conoides* (Gupta and Rastogi, 2009), *Laminaria japonica* (Esmaeili et al., 2010), and *Stoechospermum marginatum* (Mehta and Gaur, 2001) was reported. The research report implemented an efficient approach for synthesis of stable gold nanoparticles by the reduction of aqueous $AuCl_4$ by using Sargassum wightii. Recently Kumar et al. (2012) have showed that anti-bacterial activity of silver nanoparticles synthesized using Sargassum tenerrimum was comparably higher than the phytochemicals present in it.

5. Biosorption Potential of Different Nanoparticles Biosynthesised from Seaweeds

Nowadays the environment is threatened by an increase in heavy metals. Therefore, in recent years, the removal of heavy metals has become an important issue (Nurbas et al., 2002).The process of removing metal ions from aqueous solution mainly consist of physical, chemical, and biological technologies. Biological uptake is a promising approach that has been studied in the past decade. This process is a good candidate for replacing old methods (Pinto et al., 2011).

The main advantages of biological uptake are high efficiency, removal of all metals even at low concentrations, being economical, and energy independence which present this process as a feasible new technology (Bai and Abraham, 2002). In earlier research works, the absorption of copper, nickel, and cobalt by brown algae in a fixed bed reactor showed that brown algae are capable of eliminating 80 % of heavy metals from aqueous solutions (Esmaeili and Sadeghi, 2014). Comparison of Cr (VI) adsorption by dried brown algae (*Sargassum* sp.) and by activated carbon from brown algae (*Sargassum* sp.) shows that dried brown algae are more effective than activated carbon (Esmaeili et al., 2012). The biosorption process is controlled by several parameters. Pahlavanzadeh et al. (2010) investigated nickel biosorption by various species of Iranian brown algae and have expressed that the most important parameters are pH, temperature, and initial concentration. Therefore, pH is particularly importance and is dependent on the functional groups of the adsorbent and metal ions.

6. Activated Carbon using brown algae

The adsorption process with activated carbon is attracted by many scientists because of the effectiveness for the removal of heavy metal ion at trace quantities. But the process has not been used extensively for its high cost. For that reason, the use of low cost materials as sorbent for metal removal from wastewater have been highlighted. In recent times, great effort has been contributed to develop new adsorbents and improve existing adsorbents like granular activated carbon, other adsorbents such as iron oxide coated sand, porous cellulose carrier modified with polyethyleneimine etc. Activated carbon has indubitably been the most popular and widely used as adsorbent in wastewater treatment employed throughout the world. However, activated carbon remains a costly material since higher the quality of activated carbon; the greater will be its cost.

Above 2000 years ago, the activated carbon was first known to treat water. However, it was first produced commercially at the beginning of the 20th century and was only available in powder form. Various materials are used to produced activated carbon and some of the most commonly used are agriculture wastes such as coconut shell, saw dust, walnut shell, tropical wood and almond shell. Initially activated carbon was mainly used to decolorize sugar and then from 1930 for water treatment to remove taste and odor (Adinata et al., 2007). The adsorption power of the AC is in the range of 90% - 110% of the declaration value (Garcia et al., 2001). In addition, activated carbon is economically saved due to its low price but its cost is not too low enough to a large consumption of adsorption sites other than the intended compound to be removed (Kirubakaran et al., 1991). Decolorizing applications involve removal of large molecular compounds which require AC with a well-developed macropore structure. AC is employed as a color removing agent (adsorbent) due to its economic advantage over other adsorbents. It finds wide application in food, pharmaceuticals, solvent recovery, drinking water treatment, fuel cells, chemical and other process industries (Hameed and Daud, 2008). AC is non-specific adsorbents that not only bind the color components, but also the protein components and odor components (Lafi, 2001).

7. Degradation of dyes and heavy metals using TiO2/activated carbon

Currently, a number of techniques and processes including physical, chemical, and biological methods have been studied to treat the dyes from wastewater (Wang et al., 2012). For example, adsorption and photocatalysis have been considered as effective approaches for dye removal. The adsorption is a nondestructive process, by which the contaminants can be transferred from wastewater to adsorbent such as activated carbon (AC). However, the adsorption efficiency of the adsorbents after regeneration is greatly reduced (Zhang et al., 2008). In contrast, the photocatalysis is a favourable progressive oxidation process, which usually uses heterogeneoutitanium dioxide (TiO_2) as a photocatalyst to degrade the contaminants by the decomposition and oxidation processes on its surface (Zhang et al., 2008). There are some disadvantages of TiO2 with poor adsorption capacity, and is difficult to be separated and recycled from the solution used in advanced oxidation process as TiO_2 powder is easy to agglomerate.

In many countries, the researchers are looking for suitable treatments in order to remove these pollutants. The heterogeneous photocatalytic process using TiO_2 as a catalyst is one of the most promising advanced oxidation processes. This process is based on the generation of very reactive species such as hydroxyl radicals (•OH) that can oxidize a broad range of organic pollutants quickly and nonselectively.

8. Conclusion

In future research, more detailed study will provide a clear description of biomolecules and their role in mediating the synthesis of nanoparticles. The goal is to influence the rate of synthesis and improve nanoparticle stability. Moreover, research should be conducted to steer the production of TiO_2 from green synthesized nanoparticles toward increased reactivity to enhance environmental pollution degradation with minimum ecotoxicological impacts. In comparison to engineered nanoparticles, few studies confirm that biosynthesised nanoparticles are less toxic. In addition, a comprehensive risk assessment of green fabricated TiO_2 should be performed in which fate, transport, aggregation, dissolution and kinetics in processing of the nanoparticles is considered. The green nanotechnology processes, as described in this paper, provide a strong foundation for the production of a variety of biochemical or functionalised nanoparticles that can serve as building blocks in the development of new products that can be applicable in environmental restoration sectors.

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