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Review paper

Bioactive Compounds and Bioremediation Potential of Brown Algae: A Comprehensive Review

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ABSTRACT

The toxic effects of heavy metal bioaccumulation in various biological systems, including humans, animals, microorganisms, and plants, pose significant concerns for environmental health and safety. Utilizing different plant materials for the synthesis of nanoparticles is regarded as a environmentally friendly approach, as it avoids the use of harmful chemicals. This review aims to enhance our understanding of the issues related to heavy metal toxicity in contaminated ecosystems and explores viable, sustainable, and eco-friendly bioremediation technologies, particularly focusing on the mechanisms of phytoremediation for heavy metals. However, it is important not to overlook the challenges, such as biosafety assessment and genetic pollution, associated with the implementation of new strategies for cleaning up heavy metal-contaminated ecosystems, considering both ecological and greener perspectives.

1. Introduction

Marine algae encompass a diverse array of species, broadly categorized into microalgae and macroalgae. Micr oalgae, such as phytoplankton, thrive in the water column, while macroalgae, commonly known as seaweed, r ange in size from a few centimeters to several meters, with massive kelp forming underwater forests. Seawee ds are highly adaptable, inhabiting various environments where they receive sufficient light for photosynthesi s, from tidal rock pools near the shore to offshore locations several kilometers away. Algae are further classifi ed based on their pigmentation, leading to three major groups: brown algae (phaeophytes), green algae (chlo rophytes), and red algae (rhodophytes) (El-Rafie et al., 2013). Brown and red algae are typically found in low-light areas, while green algae inhabit both marine and freshwater environments.

Throughout history, coastal communities have incorporated seaweed into their diets and traditional medi cinal practices, and to this day, seaweed remains a staple food and medicinal resource in South-East Asia and

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Japan. Several studies have uncovered the rich source of biologically active compounds in seaweeds, including carbohydrates, carotenoids, polysaccharides, proteins, vitamins, and various secondary metabolites. These bio active compounds possess potent medicinal properties suitable for conventional treatments and alternative t herapies (Smit, 2004). Seaweed extracts have been found to exhibit anti-inflammatory and inhibitory effects that can be utilized in the treatment of various medical conditions and some forms of cancer(Liu et al., 2012).

Additionally, seaweeds have the ability to accumulate heavy metals (Mohamed et al., 2012), and certain s econdary metabolites from seaweeds have demonstrated anti-biological fouling properties (Sethi, 2011). Recent studies have also demonstrated the capacity of seaweed solutions to biologically reduce metal ions (C handa et al., 2010). Moreover, many macroalgae can accumulate higher levels of trace metals than those foun d in water samples from the same site, and they can produce phytochemicals of potential interest (Wada et al ., 2011). Bioremediation, utilizing the remediation capability of living organisms, is a promising option for addressing water pollution caused by organic and inorganic compounds detrimental to the environment's hea lth. It offers a cost-effective and eco-friendly approach, especially for low concentrations of contaminants where physical or chemical methods may not be feasible. Seaweeds' physiological properties and active compounds make them excellent candidates for aquaculture-based cleanup of polluted areas, particularly in the unique marine habitats of the Southwest coast of India. This review explores the biosynthesis of different metal and metal oxide nanoparticles from marine bioresources and their application in bioremediation.

2. Seaweeds and their Biomedical Importance

The use of marine plants for medicinal purposes traces back to ancient times, with the Chinese "Material Med ica" of Shen-Nung in 2007 BC being one of the earliest records. The medicinal role of algae and plankton in ancient times has been extensively described in literature (Ananthi et al., 2012; Schwimmer and Schwimmer, 1955). Marine algae, due to their diverse species, offer a vast source of various bioactive compounds with me dicinal properties.

3. Nanoparticles Biosynthesised from Seaweeds

Seaweeds, or marine macroalgae, are known for their rich phytochemical composition, including heteropolysa--ccharides, alkaloids, steroids, phenols, saponins, and flavonoids. These bioactive compounds have been found to possess the ability to reduce metal ions to nanoparticles and act as capping agents, contributing to the stability of the synthesized nanoparticles (Zaneveld, 1995).

The process of biosynthesis of nanoparticles from seaweeds involves the extraction of bioactive compounds followed by their reduction or stabilization to form nanoparticles. Various methods have been employed for the biosynthesis of nanoparticles, including the use of seaweed extracts, seaweed-derived biomolecules, and whole seaweed biomass.

One common approach is the use of aqueous extracts obtained from seaweeds. These extracts contain a range of bioactive compounds that can act as reducing and capping agents. The seaweed extract is mixed with metal ion solutions, and the reduction of metal ions to nanoparticles is facilitated by the presence of specific biomolecules in the extract. This method offers a simple and environmentally friendly approach for nanoparticle synthesis.

In addition to extracts, specific biomolecules derived from seaweeds have been utilized for nanoparticle synthesis. Proteins, phenols, flavonoids, and other phytochemicals present in seaweeds have been found to have reducing properties and can effectively convert metal ions into nanoparticles. These biomolecules can be isolated from seaweed extracts and used for controlled nanoparticle synthesis.

Furthermore, whole seaweed biomass can also be employed for nanoparticle synthesis. In this approach, the seaweed biomass acts as both a reducing agent and a stabilizing agent. The biomass is treated with metal ion solutions, and the interaction between the bioactive compounds present in the seaweed and the metal ions leads to the formation of nanoparticles. This method offers the advantage of utilizing the entire seaweed biomass and its inherent reducing and stabilizing properties.

Applications of Seaweed-Synthesized Nanoparticles Nanoparticles synthesized from seaweeds have shown great potential for various applications. The controlled synthesis of nanoparticles with specific sizes and shapes provides opportunities for tailoring their physical and chemical properties for specific applications.

In the field of medicine, seaweed-synthesized nanoparticles have been explored for drug delivery systems, imaging agents, and antimicrobial agents. The small size and large surface area of nanoparticles enable efficient drug loading and targeted deliv ery to specific cells or tissues. Additionally, the unique optical and magnetic properties of nanoparticles make them suitable for medical imaging techniques. The antimicrobial properties of some seaweed-derived nanoparticles offer potential applications in combating drug-resistant pathogens.

Nanoparticles synthesized from seaweeds also find applications in environmental remediation. Their abili ty to interact with heavy metal ions makes them useful for removing pollutants from water and soil. The nan oparticles can effectively adsorb or catalytically degrade the contaminants, contributing to the remediation of polluted environments.

Furthermore, seaweed-synthesized nanoparticles have shown promise in the fields of catalysis, optoelectronics, and sensing devices. The tunable properties of nanoparticles allow for their utilization as catalysts in various chemical reactions. In optoelectronics, nanoparticles can be incorporated into devices for enhanced light absorption and emission properties. Nanoparticles also exhibit unique sensing capabilities, ma king them valuable in the development of sensors for detecting specific analytes.

4. Therapeutic Potential of Different Nanoparticles Biosynthesised from Seaweeds

Algae, often referred to as bionanofactories, possess unique properties that make them ideal for synthesizing nanoparticles. These microscopic aquatic plants naturally produce phytochemicals that play a crucial role in t he formation of metallic nanoparticles. Several studies have reported the synthesis of gold nanoparticles usin g algae extracts, including Sargassum wightii, Turbinaria conoides, Laminaria japonica, and Stoechospermum marginatum (Esmaeili and Darvish, 2014; Gupta and Rastogi, 2009; Esmaeili et al., 2010; Mehta and Gaur, 20 01).

One such research study focused on the efficient synthesis of stable gold nanoparticles by utilizing the re duction properties of aqueous $AuCl_4$ with the extract of *Sargassum wightii*. This approach proved successful in producing gold nanoparticles with high stability (Esmaeili and Darvish, 2014).

Additionally, Kumar et al. (2012) demonstrated the synthesis of silver nanoparticles using Sargassum ten errimum and compared their antibacterial activity with the phytochemicals present in the algae. The results i ndicated that the silver nanoparticles exhibited higher antibacterial activity compared to the phytochemicals alone.

The ability of algae to synthesize nanoparticles offers several advantages. Algae can be easily handled an d do not require complex cell maintenance processes. The nanoparticles synthesized from algae extracts tend to exhibit high stability, making them suitable for various applications. Moreover, algae provide a sustainable and environmentally friendly source for nanoparticle synthesis.

In summary, algae serve as natural bionanofactories due to their capability to synthesize nanoparticles w ith high stability. The use of algae extracts, such as Sargassum species, has been successful in producing gold and silver nanoparticles, showcasing their potential for various applications including antibacterial activity an d nanomaterial production.

5. Biosorption Potential of Different Nanoparticles Biosynthesised from Seaweeds

In recent years, the increase in heavy metal pollution has posed a significant threat to the environment, prom pting the need for effective removal methods (Nurbas et al., 2002). Among various approaches, the biological uptake of heavy metals has emerged as a promising solution, gaining considerable attention in the past decad e as a viable alternative to conventional methods (Pinto et al., 2011).

Biological uptake offers several advantages, including high efficiency, the ability to remove metals even at low concentrations, cost-effectiveness, and energy independence, making it an attractive option for new technology (Bai and Abraham, 2002). Previous research has demonstrated the potential of brown algae in re moving heavy metals from aqueous solutions. In a fixed bed reactor, brown algae were found to eliminate 80 % of copper, nickel, and cobalt ions (Esmaeili and Sadeghi, 2014). Furthermore, a comparison between the adsorption of Cr (VI) by dried brown algae (Sargassum sp.) and activated carbon from brown algae (Sargassum sp.) revealed that dried brown algae exhibited higher effectiveness than activated carbon (Esmaeili et al., 2012).

The process of biosorption, where biological materials bind and remove heavy metals, is influenced by various parameters. Pahlavanzadeh et al. (2010) investigated nickel biosorption using different species of Iranian brown algae and identified pH, temperature, and initial concentration as critical factors. Among these parameters, pH is particularly crucial as it depends on the functional groups of the adsorbent and the metal ions.

6. Activated Carbon using Brown Algae

The use of activated carbon as an adsorbent for heavy metal removal has attracted the attention of scientists due to its effectiveness, especially in trace quantities. However, the high cost associated with activated carbon has limited its extensive use. Consequently, there has been a growing emphasis on exploring low-cost materials as alternatives for metal sorption from wastewater. Significant efforts have been made to develop new adsorbents and enhance existing ones, such as granular activated carbon, iron oxide coated sand, and porous cellulose carrier modified with polyethyleneimine.

Activated carbon has been widely recognized as the most popular adsorbent for wastewater treatment worldwide. It has a long history, dating back over 2000 years when it was first used for water treatment. Commercial production of activated carbon began in the early 20th century, initially in powder form. Various materials are used in its production, with agricultural waste like coconut shell, sawdust, walnut shell, tropical wood, and almond shell being among the commonly utilized sources. Initially, activated carbon was primarily employed for decolorizing sugar and later, from 1930 onwards, for water treatment to remove taste and odor (Adinata et al., 2007).

Activated carbon exhibits a strong adsorption capacity, typically ranging from 90% to 110% of its declared value (Garcia et al., 2001). While activated carbon is economically advantageous due to its relatively low cost, its overall expense is still not low enough to facilitate extensive consumption of adsorption sites for substances other than the target compound to be removed (Kirubakaran et al., 1991). Its applications in decolorization often involve the removal of large molecular compounds, necessitating activated carbon with a well-developed macropore structure. It is widely used as an adsorbent in various industries, including food, pharmaceuticals, solvent recovery, drinking water treatment, fuel cells, and chemical processes, due to its economic advantages over other adsorbents (Hameed and Daud, 2008). Activated carbon is a non-specific adsorbent that not only binds color components but also protein and odor components (Lafi, 2001).

In summary, while activated carbon has been extensively used and recognized for its adsorption capabilities in wastewater treatment, its high cost remains a limiting factor. Efforts are being made to explore alternative low-cost adsorbents, while the development and improvement of existing adsorbents continue. The diverse applications of activated carbon, primarily in decolorization processes, highlight its economic advent-ages but also underscore the need for careful consideration of its specific adsorption properties.

7. Degradation of Dyes and Heavy Metals using TiO_2/Activated Carbon

In the quest to treat dyes in wastewater, various techniques and processes, including physical, chemical, and biological methods, have been extensively studied (Wang et al., 2012). Two effective approaches for dye removal are adsorption and photocatalysis. Adsorption involves the transfer of contaminants from wastewater to an adsorbent material like activated carbon (AC), offering a nondestructive means of removal. However, the adsorption efficiency of regenerated adsorbents is significantly reduced (Zhang et al., 2008).

On the other hand, photocatalysis is a promising advanced oxidation process that utilizes heterogeneous titanium dioxide (TiO2) as a photocatalyst to degrade contaminants through decomposition and oxidation on its surface (Zhang et al., 2008). This process involves the generation of highly reactive species, such as hydroxyl radicals (•OH), which exhibit fast and nonselective oxidation of a wide range of organic pollutants.

While the heterogeneous photocatalytic process using TiO_2 as a catalyst holds great potential, there are some drawbacks to consider. TiO_2 exhibits poor adsorption capacity and poses challenges in terms of separation and recycling from the solution due to the agglomeration tendency of TiO2 powder. Researchers in many countries are actively seeking suitable treatments to address these pollutants, with a focus on the development and optimization of advanced oxidation processes, such as heterogeneous photocatalysis using TiO_2.

Overall, the use of TiO_2 as a catalyst in the photocatalytic process shows promise in efficiently degrading organic pollutants by generating highly reactive species. However, further research is needed to address the limitations associated with TiO_2, such as its adsorption capacity and recyclability, in order to enhance its practical applicability in wastewater treatment.

8. Conclusion

Future research in the field of nanotechnology should focus on conducting more detailed studies to gain a comprehensive understanding of biomolecules and their role in mediating the synthesis of nanoparticles. By elucidating the mechanisms and functions of these biomolecules, researchers can effectively control the rate of nanoparticle synthesis and enhance their stability.

Furthermore, it is crucial to explore methods to improve the reactivity of TiO2 nanoparticles synthesized through green processes. By enhancing their reactivity, these nanoparticles can be utilized more effectively in environmental pollution degradation while minimizing any potential ecotoxicological impacts.

Comparative studies between biosynthesized nanoparticles and engineered nanoparticles should be conducted to further investigate the toxicity levels associated with each. Preliminary evidence suggests that biosynthesized nanoparticles may exhibit lower toxicity compared to their engineered counterparts. A more comprehensive risk assessment should also be carried out for green fabricated TiO2 nanoparticles, taking into account factors such as fate, transport, aggregation, dissolution, and kinetics during nanoparticle processing.

The green nanotechnology processes described in this paper lay a strong foundation for the production of diverse biochemical or functionalized nanoparticles. These nanoparticles can serve as essential building blocks in the development of new products applicable to the field of environmental restoration.

Overall, future research endeavors should aim to advance our understanding of biomolecule-mediated nanoparticle synthesis, improve the reactivity of green synthesized nanoparticles, assess their toxicity levels, and explore their application potential in environmental restoration sectors. Such efforts will contribute to the development of safer and more sustainable nanotechnology practices.

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References

1. Adams, J. A., & Ready, K. R. (2003). Extent of benzene biodegradation in saturated soil column during air sparging. *Groundwater Monitoring and Remediation*, *23*(3), 85–94.
2. Adinata, D., Daud, W. M. A. W., & Mohd Kheireddine, A. (2007). Preparation and characterization of activated carbon from palm shell by chemical activation with K2CO3. Biores tech, *98*, 145–149.
3. Ananthi, S., Raghavendran, H. R. B., Sunil, A. G., Gayathri, V., Ramakrishnan, G., & Vasanthi, H. R. (2010) *In vitro* antioxidant and *invivo* anti-inflammatory potential of crude polysaccharide from *Turbinaria ornata* (Marine Brown Alga) *Food and Chem Toxi* 48 (1): 87–192.
4. Bai, R. S., & Abraham, T. E. (2002). Studies on enhancement of Cr(VI) biosorption by chemically modified biomass of *Rhizopus nigricans*. *Water Research*, *36*(5), 1224–1236.
5. Baker, S., Harini, B. P., Rakshith, D., & Satish, S. (2013). Marine microbes: Invisible nanofactories. *Journal of Pharmacy Research*, 6(3) 383–388

6. Batayneh, A. T. (2012). Toxic (aluminum, beryllium, boron, chromium and zinc) in groundwater: Health risk assessment. *International Journal of Environmental Science and Technology*, *9*(1), 153–162.
7. Chakraborty, R., Wu, C. H., & Hazen, T. C. (2010). Systems biology approach to bioremediation. *Current Opinion in Biotechnology*, *23*, 1–8.
8. Chanda, S., Dave, R., Kaneria, M., & Nagani, K. (2010). Seaweeds: A novel, untapped source of drugs from sea to combat infectious diseases in Current Research, Technology and Education Topics in Applied Microbiology and Microbial Biotechnology. In A. Mendez-Valas (Ed.), *Formatex research center, Badazoj, Spain* (pp. 473–480).
9. Conesa, H. M., Evangelou, M. W. H., Robinson, B. H., & Schulin, R. (2012). A critical view of current state of phytotechnologies to remediate soils: Still a promising tool? *TheScientificWorldJournal*, *2012*, 173829.
10. Dhamotharan, R., Punitha, D., Murugesan, S., & Subha, T. S. (2010). Brown algal biomass mediated biosynthesis of gold nanoparticles. *International Journal of Nanotechnology*Sci & Nanotech 1, 33–40.
11. Dua, M., Sethunathan, N., & Johri, A. K. (2012). Biotechnology bioremediation success and limitations. *Applied Microbiology and Biotechnology*, *59*(2), 143–152.
12. El Gamal, A. A. (2010). Biological importance of marine algae. *Saudi Pharmaceutical Journal*, *18*(1), 1–25.
13. Esmaeili, A., & Darvish, M. (2014). Evaluation of the marine alga *Sargassum glaucescens* for the adsorption of Zn(II) from aqueous solutions. *Water Quality Research Journal*, *49*(4), 339–345.
14. Esmaeili, A., Ghasemi, S., & Zamani, F. (2012a). Investigation of Cr(VI) adsorption by dried brown algae *Sargassum* sp. and its activated carbon. *Iranian Journal of Chemistry and Chemical Engineering*, *31*(4), 11–19.
15. Garcia, F. S., Alonso, A. M., & Tascon, J. M. D. (2001). Porous texture of activated carbons prepared by phosphoric acid activation of apple pulp. *Carbon*, *39*, 1103–1106.
16. Gupta, V. K., & Rastogi, A. (2009). Biosorption of hexavalent chromium by raw and acid-treated green alga *Oedogonium hatei* from aqueous solutions. *Journal of Hazardous Materials*, *163*(1), 396–402.
17. Ismail, B. S., Farihah, K., & Khairiah, J. (2005). Bioaccumulation of heavy metals in vegetables from selected agricultural areas. *Bulletin of Environmental Contamination and Toxicology*, *74*(2), 320–327.
18. Kensa, M. V. (Bioremediation: an overview. (2011). *Journal of Industrial Pollution Control*, *27*(2), 161–168.
19. Khan, M. N. A., Choi, J. S., Lee, M. C., Kim, E., Nam, T. J., Fujii, H., & Hong, Y. K. (2008). Anti-inflammatory activities of methanol extracts from various seaweed species. *Journal of Environmental Biology*, *29*(4), 465–469.
20. Kim, J. S., Kuk, E., Yu, K. N., Kim, J. H., Park, S. J., Lee, H. J. (2007). Antimicrobial effects of silver nanoparticles. *Nanomedicine: Nanotechnology, Biology, and Medicine*, *3*(1), 95–101.
21. Kim, S. K. (2011). *Handbook of marine macroalgae*. Chichester, UK: Biotech and App Phy JohnWiley & Sons.
22. Liu, L., Heinrich, M., Myers, S., & Dworjanyn, S. A. (2012). Towards a better understanding of medicinal uses of the brown seaweed *Sargassum* in Traditional Chinese Medicine: A phytochemical and pharmacological review. *Journal of Ethnopharmacology*, *142*(3), 591–619.
23. Malaviya, P., & Singh, A. (2011). Physiochemical technologies for remediation of chromium-containing waters and wastewaters. *Critical Reviews in Environmental Science and Technology*, *41*(12), 1111–1172.
24. Mehta, S. K., & Gaur, J. P. (2001). Removal of Ni and Cu from single and binary metalsolutions by free and immobilized *Chlorella vulgaris*. *European Journal of Protistology*, *37*(3), 261–271.
25. Nishino, T., Fukuda, A., Nagumo, T., Fujihara, M., & Kaji, E. (1999). Inhibition of the generation of thrombin and factor Xa by a fucoidan from the brown seaweed *Ecklonia kurome*. *Thrombosis Research*, *96*(1), 37–49.
26. Nurbas¸ N. M., Kilic Arslan, S., Ilhan, S., & Ozdag, H. (2002). Biosorption of Cr6? Pb2? and Cu2? ions in industrial waste water on *Bacillus sp*. *Chemical Engineering Journal*, *85*, 351–355.
27. Pahlavanzadeh, H., Keshtkar, A. R., Safdari, J., & Abadi, Z. (2010). Biosorption of nickel(II) from aqueous solution by brown algae: Equilibrium, dynamic and thermodynamic studies. *Journal of Hazardous Materials*, *175*(1–3), 304–310.
28. Pilon-Smits, E. (2005). Phytoremediation. *Annual Review of Plant Biology*, *56*(1), 15–39.
29. Pinto, P. X., Al-Abed, S. R., & Reisman, D. J. (2011). Biosorption of heavymetals from mining influenced water onto chitin products. *Chemical Engineering Journal*, *166*(3), 1002–1009.
30. Schwimmer, D., & Schwimmer, M. (1995). Algae and Medicine. In F. Jackson Plenum (Ed.), *Algae and man* (pp. 368–412). New York.
31. Tang, C. Y., Fu, Q. S., Criddle, C. S., & Leckie, J. O. (2007). Effect of flux (Transmembrane pressure) and membranes properties on fouling and rejection of reverse osmosis and nanofiltration membranes treating perfluorooctane sulfonate containing wastewater. *Environmental Science and Technology*, *41*(6), 2008–2014.
32. Vijayaraghavan, K., Mahadevan, A., Sathishkumar, M., Pavagadhi, S., & Balasubramanian, R. (2011). Biosynthesis of Au (0). *Chemical Engineering Journal*, *167*(1), 223–227.

33. Wada, K., Nakamura, K., & Tamai, Y. (2011). Seaweed intake and blood pressure levels in healthy pre-school Japanese children. *Nutrition Journal*, *10*, 198–221.
34. Zaneveld, J. S. (1995). The Utilization of marine algae in Tropical South and East and Asia. *Jurnal Economia Bot*, *13*(2), 89–131.
35. Zhang, C., Long, D., Xing, B., Qiao, W., Zhang, R., Zhan, L., … Ling, L. (2008). The superior electrochemical performance of oxygen-rich activated carbons prepared from bituminous coal. *Electrochemistry Communications*, *10*(11), 1809–1811.
36. Zuercher, A. W., Fritsché, R., Corthésy, B., & Mercenier, A. (2006). Food products and allergy development, prevention and treatment. *Current Opinion in Biotechnology*, prevention and treatment. Cur Opi Biotech, 17(2), 198–203.