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Mini Review

Cyanobacteria: Symbiosis with the Sea - A Mini-Review on their Role in Advancing the Blue Economy

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Abstract

The concept of the Blue Economy, which emphasizes industries based on the ocean, has made cyanobacteria important players. The numerous ways that cyanobacteria contribute to the aquaculture, bioenergy, bioremediation and pharmaceutical industries are examined in this mini-review. This article summarizes current developments and cyanobacteria research initiatives that are promoting economic growth, sustainability and innovation in the marine environment. Cyanobacteria are showing to play a significant role in determining the direction of the Blue Economy, both through their production of bioactive compounds and their role in sequestering carbon.

Keywords: Cyanobacteria; Symbiosis; Marine ecosystem; Blue economy impact

Introduction

Blue-green algae or cyanobacteria, are microorganisms that are essential to aquatic environments because they can produce oxygen and carry out photosynthesis. Cyanobacteria are considered potential assets in the blue economy, which focuses on the sustainable utilization of ocean resources [1-3]. The cultivation of cyanobacteria provides a source of biomass rich in lipids for biofuels, helping to reduce reliance on fossil fuels and mitigate climate change. They are investigated for the production of bioenergy. By absorbing and fixing atmospheric nitrogen during the nutrient cycle, cyanobacteria improve water quality and promote aquatic health. By absorbing pollutants and heavy metals, their bioremediation ability helps to improve the environment. Additionally, cyanobacteria are used as a sustainable feed substitute for prawns and fish in aquaculture. Their bioactive compounds also have potential for use in biotechnological and pharmaceutical applications, which could create jobs and protect marine biodiversity. Notwithstanding these opportunities, a comprehensive and long-term integration of cyanobacteria into the blue economy necessitates careful consideration of issues like scalability, harmful algal blooms and environmental impact assessments [4-6].

Bioenergy Production

The utilization of cyanobacteria as a renewable source of biofuels and their unique ability to perform photosynthesis has led to recent advancements in their harnessing for bioenergy production. Acknowledged for their proficient photosynthetic apparatus, cyanobacteria effectively transform solar radiation into chemical energy. In order to increase biomass production and total bioenergy output, researchers are focusing a great deal of effort on optimizing cyanobacterial photosynthetic processes [7,8]. Utilizing genetic engineering methods, strains with higher lipid contents which are essential for the production of biodiesel are developed in order to improve the efficiency of light-harvesting and carbon fixation. In hybrid approaches, cyanobacteria are combined with other microorganisms to form symbiotic relationships that increase overall productivity and increase the variety of biofuels produced. Developing unique metabolic pathways and enhancing cyanobacteria's capacity to produce bioenergy by introducing characteristics like enhanced stress tolerance, elevated lipid accumulation, and elevated biomass productivity are made possible through the application of synthetic biology techniques. The ability to extract value-added products from cyanobacterial biomass through integration into biorefinery concepts increases the financial sustainability of cyanobacteria-based bioenergy systems. Large-scale cultivation is focusing on outdoor systems to address issues such as contamination and environmental fluctuations [9,10].

Bioremediation and Water Quality

Cyanobacteria are essential to marine bioremediation because they greatly enhance the purification of water. Water quality is improved by their ability to absorb excess nutrients, pollutants and heavy metals [11]. Cyanobacteria are known for their ability to fix nitrogen from the atmosphere. They lower nitrogen levels in aquatic ecosystems, which help to address issues such as eutrophication, which is caused by excessive growth of algae and toxic algal blooms caused by elevated levels of phosphorus and nitrogen. Apart from nitrogen, cyanobacteria also help remove excess phosphorus, which is important to keep eutrophication from happening. Toxins released during toxic algal blooms can be broken down by certain cyanobacterial strains, reducing the effects on humans and aquatic life. Heavy metals such as copper, lead and cadmium are accumulated by cyanobacteria, which act as efficient sinks and aid in bioremediation in metal-contaminated areas. Their mat and filament structures produce microenvironments for chemical reactions that further aid in aquatic purification, as well as physical barriers on sediments that prevent the release of nutrients and pollutants [2,12].

Pharmaceutical Applications

The potential pharmaceutical uses of cyanobacteria, which are known to be abundant in bioactive compounds, have attracted interest. Different compounds from cyanobacteria with promising pharmacological properties have been revealed recently. The antimicrobial compounds and antibiotics generated by cyanobacteria demonstrate effectiveness against various pathogens, implying potential uses in the fight against bacteria that are resistant to drugs [2,13]. Cyanobacterial compounds exhibit noteworthy antibacterial and antifungal properties, presenting opportunities for novel therapeutic agents. Cyanobacterial metabolites exhibit anticancer activity and cytotoxic effects on different cancer cell lines in preclinical studies, suggesting that they may develop into anticancer agents. Moreover, cyanobacteria generate neuroprotective substances that may be used to treat neurodegenerative illnesses including Parkinson's and Alzheimer's. Opportunities exist for the development of medications that target diseases such as rheumatoid arthritis and inflammatory bowel disorders. Furthermore, compounds with antiviral qualities derived from cyanobacteria are being studied for possible antiviral medication development. Because cyanobacteria have antioxidant qualities, they can be used in skincare products and anti-aging formulations to prevent oxidative damage to skin cells. Cyanobacterial compounds immunomodulatory properties may be useful in treating immune-related illnesses [14].

Cyanobacteria and Climate Resilience

Through active carbon sequestration and mitigation of the effects of climate change on ocean health, cyanobacteria are essential for enhancing climate resilience within marine ecosystems. Their effective photosynthesis helps to reduce atmospheric CO_2 by converting carbon dioxide into organic carbon. This process contributes to carbon sequestration. Certain cyanobacteria aid in the creation of marine carbonate deposits, such as stromatolites and microbialites, which support the resilience of marine ecosystems and enable long-term carbon storage [15,16]. Furthermore, cyanobacteria aid in the stabilization of sediment in marine environments, halting erosion and preserving the integrity of coastal ecosystems. Because cyanobacteria can fix atmospheric nitrogen, marine ecosystems have better access to nutrients, which promotes the growth of other plants. In the context of changes in temperature, acidity and nutrient availability brought on by climate change, their capacity to adapt to a variety of environmental conditions is essential for maintaining the stability of marine ecosystems [15]. Additionally, cyanobacteria produce oxygen through photosynthesis, which is essential for preserving aerobic conditions in marine environments and promoting the wellbeing of marine organisms that depend on oxygen for survival.

Challenges and Future Perspectives

There is a lot of potential for integrating cyanobacteria into the Blue Economy, however one of the challenges is the release of toxins by Harmful Algal Blooms (HABs), which can be mitigated by genetic modification, early detection and monitoring. The ecological effects of large-scale cultivation necessitate environmental assessments and sustainable practices. Investments in research are necessary due to technological constraints, and pilot projects and standardized protocols are necessary for scaling up. Strict containment measures are required due to biosecurity concerns, and public awareness and regulatory support are necessary for market acceptance. A comprehensive and sustainable strategy that ensures the economic benefits of cyanobacteria without sacrificing environmental resilience and societal well-being requires interdisciplinary collaboration.

Conclusion

In summary, blue-green algae or cyanobacteria, have great potential to improve a number of Blue Economy components. They can be important resources for the sustainable use of ocean resources, as demonstrated by their roles in bioenergy production, bioremediation, pharmaceutical applications and climate resilience. Notwithstanding their many advantages, there are certain problems that need to be properly resolved, like hazardous algal blooms, environmental effects and scaling. Successful integration of cyanobacteria into the Blue Economy demands interdisciplinary collaboration, technological advancements, stringent regulatory frameworks and public awareness to ensure both economic prosperity and environmental sustainability.

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