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Marine Bio-waste to Biostimulants: A Sustainable Solution for Agriculture

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Abstract

Marine biowaste-derived biostimulants hold great potential to revolutionize agriculture, ensuring food security, environmental sustainability, and resource efficiency in the face of global climate challenges. Marine biowaste, primarily sourced from seafood processing industries, includes shells, exoskeletons, and other organic residues rich in bioactive compounds like chitin, proteins, and minerals. These components can be effectively converted into value-added products, such as chitosan, peptides, and biofertilizers, which enhance plant growth, soil health, and stress resistance. In order to encourage sustainable farming by lowering dependency on chemical pesticides and fertilizers, chitosan biostimulants have been widely investigated. In addition to improving soil microbiota and nutrient absorption, they increase plants' resistance to both biotic and abiotic environmental stress factors, leading to reduced crop losses and enhanced production. In this article, benefits of the circular economy and usefulness of deploying especially chitosan-based biostimulants in the context of sustainable agriculture have been critically discussed.

Introduction

Agriculture faces unprecedented challenges in the 21st century. Feeding a growing global population amidst climate change, soil degradation, and declining natural resources necessitates innovative and sustainable approaches. Traditional chemical fertilizers and pesticides have often exacerbated these issues, prompting a shift towards eco-friendly alternatives. One promising avenue is the utilization of marine biowaste to create biostimulants — natural, sustainable solutions that enhance plant growth, improve soil health, and increase agricultural productivity (Zhang et al., 2024). Marine biowaste, such as fishery by-products and algae residues, is a rich source of organic compounds, proteins, and micronutrients, offering immense potential for recycling into value-added products. Biostimulants derived from these resources improve plant growth, enhance nutrient uptake, and increase resilience to stress, contributing to more sustainable agricultural practices (Rudovica et al., 2021). Transforming marine-waste to functional biostimulants aligns with the key principles of circular economy by closing nutrient loops, reducing the environmental footprint of agricultural inputs, and minimizing reliance on synthetic fertilizers (Kim and Mendis, 2006; Duque-Acevedo et al., 2020). Furthermore, it addresses pressing global challenges, including marine waste management and soil degradation, by creating synergies between waste reduction and agricultural productivity. Of various marine bio-waste materials, chitosan derived from crustacean shells stands out as a powerful biostimulant with remarkable potential for sustainable agriculture. This article explores the role of chitosan-based biostimulants, their benefits, applications, and challenges.

Chitosan is a natural polysaccharide derived from chitin, a major component of crustacean shells such as shrimp, crab, and lobster (Ngasotter et al., 2023). Chitin is processed through deacetylation to produce chitosan, a compound with unique biological properties. Chitosan has been extensively studied for its antimicrobial, antifungal, and plant growth-promoting effects, making it an ideal candidate for agricultural applications. Chitosan-based biostimulants are gaining attention due to their ability to improve crop productivity, enhance plant stress tolerance, and reduce reliance on chemical inputs. Their biodegradability and eco-friendliness further position them as a sustainable solution for modern farming challenges.

Structurally, chitosan is a linear polysaccharide derived from chitin, composed of β-(1→4)-linked D-glucosamine (deacetylated units) and N-acetyl-D-glucosamine (acetylated units) (Aranaz et al., 2021). Its structure is defined by the degree of deacetylation (DDA), which determines the ratio of free amino groups and influences solubility, reactivity, and bioactivity (Jiménez-Gómez and Cecilia, 2020; Pellis et al., 2022). Typically, commercial chitosan has a DDA of 70-90%, making it cationic in acidic solutions due to its amino groups. This unique characteristic enables interactions with negatively charged molecules, contributing to its diverse functionalities. The presence of amino (-NH2) and hydroxyl (-OH) groups (figure 1) allows for extensive modifications, such as improving solubility or introducing bioactive functionalities (Yadav et al., 2023)

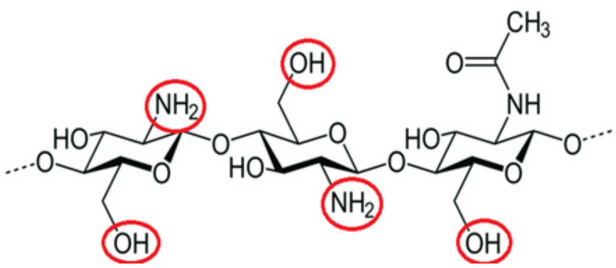

Figure 1. Chemical structure of bioactive chitosan polymer

Chitosan's structural properties are foundational to its applications in agriculture, pharmaceuticals, water treatment, and biomedicine, where its bio-adhesive, biodegradable, and biocompatible nature is leveraged effectively (Ngasotter et al., 2023).

Commercial Production of Chitosan from Marine bio-waste

Chitosan is commercially synthesized from marine bio-waste, primarily the exoskeletons of crustaceans such as shrimp, crabs, and lobsters. These by-products are rich in chitin, a polysaccharide that serves as the precursor for chitosan. The conversion process involves chemical modifications, including deproteinization with alkali treatments to remove protein content and demineralization with acids to eliminate calcium carbonate and other minerals (as shown in figure 2). Finally, deacetylation using concentrated alkali transforms chitin into chitosan by reducing the acetyl group content in its molecular structure (Pellis et al., 2022)

This production pathway highlights a circular economy approach, leveraging seafood industry waste to produce high-value biomaterials. However, the reliance on sodium hydroxide (NaOH) and hydrochloric acid (HCl) introduces challenges related to chemical handling and environmental management. Current research focuses on optimizing enzymatic and green chemistry alternatives to enhance sustainability and reduce the ecological footprint of the production process.

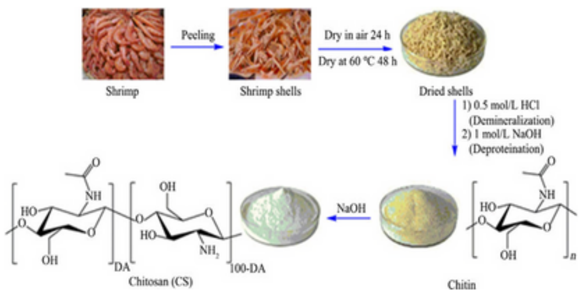

Figure 2. Commercial chitosan production from shrimp (marine bio-waste)

Benefits of Chitosan-based Biostimulants in sustainable agriculture

Recently, sustainable agriculture has emerged as a critical focus for addressing global food security and environmental challenges. Among the many innovative solutions, chitosan biostimulants have gained attention for their multifaceted benefits in enhancing crop productivity and soil health. Derived from the shells of crustaceans such as shrimp and crabs, chitosan is a natural biopolymer with remarkable properties that can transform traditional farming practices. Chitosan is chemically derived from chitin, a component of crustaceans' exoskeletons. Its unique structure and functional groups give it bioactive properties, allowing it to act as a biostimulant. The versatility of chitosan biostimulants allows for various modes of application, including foliar sprays, soil amendments, and seed coatings. Key benefits of using chitosan-based biostimulants in agriculture have been summarized in the Table 1.

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Table 1: Potentials of chitosan-based biostimulants

Merits of chitosan biostimulants in agriculture	Mode of activity
a) Stimulates plant growth	Chitosan stimulates the production of like auxins and gibberellins, which are critical for seed germination, root elongation and shoot enlargement leading to increased biomass and overall plant vigor.
b) Enhances plant immunity against both biotic and abiotic stress factors	Chitosan triggers plant defense mechanisms by inducing the production of phytoalexins, pathogenesis-related proteins, and other defense compounds. It also exhibits antimicrobial properties by disrupting cell walls of harmful fungi and bacteria, resulting in minimum crop loss due to pests and diseases. Furthermore, chitosan strengthens plant cell walls and induces the production of stress-related proteins, enabling plants to withstand drought, salinity, and temperature fluctuations.
c) Improves nutrient absorption	It facilitates better nutrient uptake and utilization by enhancing root architecture and promoting beneficial microbial interactions in the rhizosphere, leading to healthier plants and higher yields.
d) Improves soil-microbial health	Chitosan stimulates beneficial soil microbes, including nitrogen-fixing bacteria and mycorrhizae, leading to healthy rhizospheric region and improved soil biodiversity.
e) Environmentally friendly	Biodegradable and non-toxic, chitosan is a sustainable alternative to synthetic agrochemicals. It reduces environmental pollution while maintaining soil and ecosystem health.
f) Enhances shelf-life of agri-produce	Chitosan forms a protective coating, reducing microbial spoilage and water loss leading to prolonged freshness and reduced post-harvest losses.

(Source: Ngasotter et al., 2023)

Challenges and future directions

Despite its advantages, the adoption of chitosan biostimulants faces challenges. The cost of production and the need for consistent quality standards can be barriers for widespread use. However, advancements in biotechnology and the development of cost-effective production methods hold promise for making chitosan more accessible to farmers globally.

Future research is focusing on optimizing formulations and exploring synergistic effects with other biostimulants. Integrating chitosan into precision agriculture systems could further enhance its efficacy, paving the way for smarter, more sustainable farming practices.

Conclusion

Chitosan-derived biostimulants offer a sustainable and innovative solution for modern agriculture. By enhancing crop productivity, improving soil health, and reducing chemical inputs, they address key challenges faced by farmers worldwide. Leveraging this marine-based resource not only supports environmental sustainability but also contributes to the economic growth of coastal communities. With continued research and policy support, chitosan-based biostimulants have the potential to transform agriculture into a greener and more resilient industry.

References

- Aranaz, I., Alcántara, A. R., Civera, M. C., Arias, C., Elorza, B., Heras Caballero, A., & Acosta, N. (2021). Chitosan: An overview of its properties and applications. Polymers, 13(19), 3256.
- Duque-Acevedo, M., Belmonte-Ureña, L. J., Yakovleva, N., & Camacho-Ferre, F. (2020). Analysis of the circular economic production models and their approach in agriculture and agricultural waste biomass management. International Journal of Environmental Research and Public Health, 17(24), 9549.
- Jiménez-Gómez, C. P., & Cecilia, J. A. (2020). Chitosan: a natural biopolymer with a wide and varied range of applications. Molecules, 25(17), 3981.
- Kim, S. K., & Mendis, E. (2006). Bioactive compounds from marine processing byproducts–a review. Food research international, 39(4), 383-393.
- Ngasotter, S., Xavier, K. M., Meitei, M. M., Waikhom, D., Pathak, J., & Singh, S. K. (2023). Crustacean shell waste derived chitin and chitin nanomaterials for application in agriculture, food, and health–A review. Carbohydrate Polymer Technologies and Applications, 100349.
- 3.Pellis, A., Guebitz, G. M., & Nyanhongo, G. S. (2022). Chitosan: sources, processing and modification techniques. Gels, 8(7), 393.
- 4.Rudovica, V., Rotter, A., Gaudêncio, S. P., Novoveská, L., Akgül, F., Akslen-Hoel, L. K., & Burlakovs, J. (2021). Valorization of marine waste: use of industrial by-products and beach wrack towards the production of high added-value products. Frontiers in Marine Science, 8, 723333.
- Yadav, M., Kaushik, B., Rao, G. K., Srivastava, C. M., & Vaya, D. (2023). Advances and challenges in the use of chitosan and its derivatives in biomedical fields: a review. Carbohydrate Polymer Technologies and Applications, 5, 100323.
- Zhang, X., Yin, J., Ma, Y., Peng, Y., Fenton, O., Wang, W., & Chen, Q. (2024). Unlocking the potential of biostimulants derived from organic waste and by-product sources: Improving plant growth and tolerance to abiotic stresses in agriculture. Environmental Technology & Innovation, 103571.