UNIVERSITY OF LIFE SCIENCES ”KING MIHAI I” FROM TIMISOARA
”YOUNG PEOPLE AND MULTIDISCIPLINARY RESEARCH IN APPLIED LIFE SCIENCES”

05-06 November 2026



CHITOSAN-BASED BIOPREPARATIONS FOR SUSTAINABLE AGRICULTURE: FROM FUNCTIONAL PROPERTIES TO FORMULATION AND PLANT GROWTH APPLICATIONS

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Abstract: *Abstract. Chitosan is a biodegradable biopolymer with valuable functional properties and significant potential for the development of biopreparations intended for sustainable agriculture. Due to its physicochemical and biological characteristics, it can contribute to stimulating seed germination, plant growth, and development, as well as to the producing of formulation systems that facilitate the application and enhance the efficacy of active substances. This paper aims to highlight relevant and significant data from the specialized literature regarding the use of chitosan in the production of agricultural biopreparations, focusing on its functional properties, formulation methods, and potential for combination with other biopolymers. Published information concerning various application areas is utilized, alongside findings that underscore chitosan's potential to support plant physiological processes and contribute to the development of formulations tailored to the requirements of modern agriculture. By synthesizing and correlating available data, this paper provides an overview of the progress made in this field, highlighting both reported advantages and areas that require further research. An analysis of existing scientific contributions can help identify promising pathways for optimizing formulations, improving the efficacy of biopreparations, and expanding the potential uses of chitosan in agriculture. Furthermore, an understanding of the results obtained from reported research serves as an important starting point for establishing new experimental approaches and designing innovative solutions based on biopolymers. In this context, harnessing the potential of chitosan can contribute to the development of effective biopreparations and the promotion of more environmentally friendly agricultural practices, in line with the goals of sustainable agriculture.*

• Introduction

The valorization of fishery waste enables the recovery of chitin and chitosan, valuable biopolymers with potential agricultural applications (Coppola et al., 2021; Singh et al., 2022). Their use is particularly relevant given the negative environmental impacts of excessive fertilizers and pesticides, highlighting the need for sustainable alternatives (Zhang et al., 2020; Staley et al., 2015).

Natural biopolymers can support the development of biodegradable biofertilizers, biopesticides, and biostimulants (Chakraborty et al., 2023; Marwal et al., 2022). Among them, chitosan stands out due to its bioactive properties and ability to act as a carrier for active substances and beneficial microorganisms.

This study reviews chitosan-based formulations and their potential to promote plant growth and support sustainable agriculture.

• Material and method

The study is based on a critical analysis of specialized literature identified in the ScienceDirect Freedom Collection database and in open-access scientific publications. Both review articles and experimental studies were analyzed, covering the properties of chitosan, the preparation and characterization of chitosan-based formulations, and their application in agriculture. The selected literature was examined comparatively, focusing on the types of, application strategies, and key reported results regarding effects on plant growth and development, with an emphasis on the potential for use in protected-cultivation horticulture.

• Results and discussions

Chitosan is a natural biopolymer obtained by the deacetylation of chitin, a structural polysaccharide found in crustacean exoskeletons (Alemu et al., 2023).

Both polymers consist of glucosamine and N-acetylglucosamine units linked by β-(1→4) bonds. Their main structural difference is the degree of acetylation. Chitosan contains free amino groups, whose protonation in acidic conditions enables its solubility in aqueous solutions. Its properties depend mainly on molecular weight, degree of acetylation, and pH (Ghormade et al., 2017; Aranaz et al., 2009).

Chitin occurs in three crystalline forms (α, β, and γ), differing in polymer chain arrangement. α-chitin, commonly found in crustacean shells, is the main raw material used to produce chitosan (Namboodiri et al., 2020; Singh et al., 2017).

Chitosan production involves three main stages: demineralization, deproteinization, and deacetylation. These processes remove minerals and proteins and convert chitin into chitosan through the removal of acetyl groups, with final properties depending on processing conditions (Jiménez-Gómez et al., 2020).

Chitosan has reported antioxidant, antimicrobial, and antifungal properties, making it suitable for various formulation systems (Ways et al., 2018; Azuma et al., 2015; Avelelas et al., 2019). In agriculture, it is used both as a bioactive agent and as a carrier in solutions, nanoparticles, hydrogels, and biodegradable films, supporting plant growth, water retention, and controlled release of active substances. Its effectiveness depends on its molecular weight and degree of acetylation (Aranaz et al., 2009; Jiang et al., 2017).

Table 1 presents representative studies on the use of chitosan-based formulations in agriculture, highlighting their application methods, the main experimental results, and the contribution of chitosan to plant growth promotion, seed germination, and improved agricultural practices. The selected studies illustrate the versatility of chitosan as a bioactive agent, seed-coating material, nanoparticle carrier, soil amendment, and component of biodegradable films.

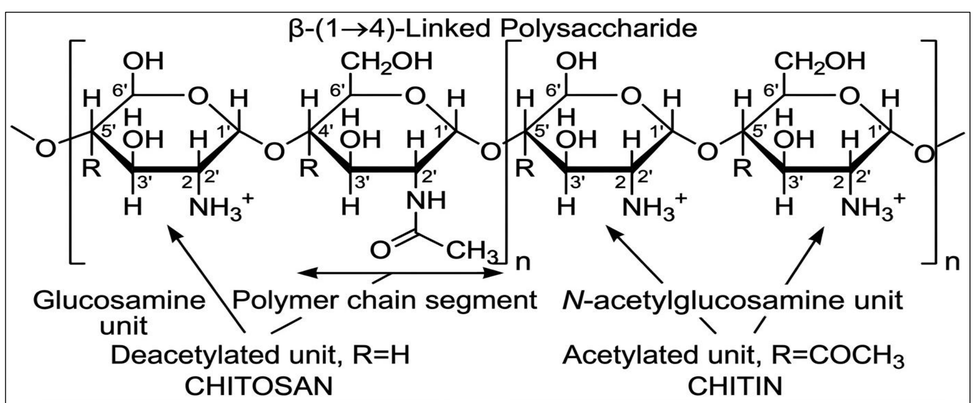


Figure 1. Chitin and chitosan

Table 1. Representative applications of chitosan-based formulations in agriculture

Formulation type and study	Best-performing variant / main results	Contribution of chitosan
Foliar solution – tomato (El Amerany et al., 2022)	Chitosan extracted from shrimp shells was dissolved in 0.05% acetic acid and applied foliarly at concentrations of 0.25, 0.50, 0.75, and 1 mg/mL every two weeks. The 0.75 mg/mL treatment increased leaf area by approximately 11% and shoot fresh biomass by 16%, while 0.50 mg/mL increased total fruit weight by approximately 57%. The 1 mg/mL treatment reduced fruit size and water content.	Chitosan acted as a bioactive agent that stimulated vegetative growth and fruit production. The results demonstrated a concentration-dependent response, indicating that higher concentrations do not necessarily produce better outcomes.
Seed coating – common bean and sesame (Godínez-Garrido et al., 2022)	Chitosan coatings at concentrations of 0.1%, 0.5%, and 1%, including formulations containing chitosan flakes and acrylic resin, produced continuous and uniform films. Germination increased by up to 26% in common bean and 16% in sesame, while root length increased by up to 77% in common bean and fourfold in sesame.	Chitosan served as a seed-coating material, forming a film around the seeds and supporting germination and early root development.
Gibberellic acid (GA_3)-loaded nanoparticles – common bean (Pereira et al., 2017)	Two delivery systems were tested: alginate/chitosan (ALG/CS) and chitosan/tripolyphosphate (CS/TPP), both loaded with GA_3 at 50 µg/mL. Encapsulation efficiency reached 100% for ALG/CS and 90% for CS/TPP. The ALG/CS system increased leaf area by approximately 78%, whereas CS/TPP promoted root elongation under certain conditions.	Chitosan formed part of the nanoparticle matrix used to deliver the plant growth regulator. It contributed to encapsulation and delivery, while plant responses depended on the composition of the overall formulation.
Soil-applied nanochitosan – tomato (Shanmugavel and Solorza-Feria, 2026)	Nanochitosan produced from blue crab exoskeletons using ionic gelation with tripolyphosphate had an average particle size of 38.8 nm. Application at 5 mg per 15 kg of soil increased soil moisture from 22% to 39%, water-holding capacity from 70% to 84%, and total nitrogen from 1.4 to 3.8 g/kg. Favorable effects on root and shoot development, flowering, and fruit quality were also reported.	Nanochitosan acted as a soil amendment associated with improved water retention and soil nutrient status. Further validation under field conditions is needed.
Encapsulation of Pseudomonas fluorescens (Isabel et al., 2024)	A formulation containing 3% chitosan maintained bacterial viability at approximately $7x10^{10}$ CFU/mL for ten months. Application to tomato plants was associated with improved plant growth and fruit development.	Chitosan served as a protective carrier for a beneficial microorganism used in biofertilization, supporting microbial survival during storage and application.
Sprayable biodegradable mulch – ornamental shrubs (Giaccone et al., 2018)	The formulation contained 1.5% chitosan, 3% acetic acid, polyglycerol, cellulose fibres, and carbon black and was applied at 2 L/m^2. Weed emergence was suppressed for more than two months, with no apparent phytotoxic effects. Weeds reappeared as the film degraded.	Chitosan contributed to the formation of a biodegradable film that acted as a physical barrier against weed emergence. Its main function in this application was weed control rather than direct stimulation of plant growth.

• Conclusions

Chitosan is a highly versatile, biodegradable biopolymer with significant potential for enhancing stress tolerance, thereby promoting plant growth and development.

The diversity of available chitosan formulations—and their combination with nutrients or beneficial microorganisms—supports the producing of sustainable biopreparations, the efficacy of which depends on their composition and the conditions under which they are applied.

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