

Entomological and marine sources of chitosan: A review of its properties and biopolymer applications

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Abstract

Chitosan, a biopolymer obtained through the partial deacetylation of chitin, is widely valued for its biocompatibility, biodegradability, and functional versatility. Traditionally sourced from marine crustaceans, chitosan has recently gained attention from entomological origins, particularly due to ecological concerns and allergenic issues associated with marine sources. Insect-derived chitosan presents a sustainable and underutilized alternative with comparable physicochemical properties and added environmental benefits. This review explores the major biological sources of chitosan, focusing on insects and marine organisms, and highlights their impact on polymer quality and application potential. The intrinsic properties of chitosan such as cationic nature, mucoadhesion, antimicrobial activity, and ease of chemical modification support its wide-ranging use in pharmaceuticals, biomedicine, agriculture, food preservation, and environmental remediation. Notably, its application in drug delivery systems, wound healing, tissue engineering, and gene therapy demonstrates its promise as a next-generation biomaterial. Advancements in formulation science and nanotechnology further enhance chitosan's adaptability across sectors. This review underscores the importance of expanding entomological sources of chitosan as a sustainable, cost-effective, and eco-conscious strategy, bridging biomaterial science with environmental responsibility. As research advances, insect-sourced chitosan is poised to play a pivotal role in addressing global challenges through innovative biopolymer applications.

Keywords: Chitosan, insect-derived biopolymer, marine sources, biocompatibility, biodegradability, sustainable materials

Introduction

Chitin, a structural polysaccharide forming the exoskeleton of arthropods such as insects and crustaceans, as well as the cell walls of fungi, is recognized as the second most abundant natural biopolymer after cellulose [1]. Among these sources, insects present a particularly sustainable and underutilized alternative for chitin and chitosan extraction, offering ecological and economic benefits relevant to entomological and material science research. Through partial deacetylation of chitin, chitosan is obtained as a functional amino polysaccharide with broad applications across multiple scientific disciplines, including entomology, pharmaceuticals, and biomaterials. In the context of entomology, the study and utilization of insect-derived chitosan not only contribute to sustainable biopolymer production but also open avenues for the development of bioinspired materials and insect-based biomedical models. Chitosan derived from insects displays comparable physicochemical properties to that obtained from crustaceans, including solubility in acidic environments due to protonated amino groups, cationic surface charge, and ease of functional modification [2]. These characteristics facilitate interactions with negatively charged molecules, including biological membranes and nucleic acids, making chitosan suitable for a wide range of bioapplications. Biocompatibility, biodegradability, low toxicity, and mucoadhesiveness further enhance chitosan's appeal as a multifunctional biomaterial. In pharmaceutical applications, it is employed as a carrier to improve drug solubility, stability, and controlled release. Formulations such as nanoparticles, hydrogels, microspheres, and biofilms utilize chitosan to deliver therapeutics effectively. Its

mucoadhesive nature is particularly beneficial in non-invasive drug delivery routes like nasal, ocular, and buccal pathways, where it prolongs residence time and enhances absorption [3]. Moreover, chitosan-based nanocarriers have demonstrated promising results in cancer therapy, gene delivery, vaccine administration, and wound healing, owing to their efficient cellular uptake and modifiable surface chemistry [4]. Beyond its role in drug delivery, chitosan also exhibits intrinsic biological properties such as antimicrobial, antioxidant, anti-inflammatory, and anticancer activities [5]. These effects are influenced by intrinsic variables like molecular weight and degree of deacetylation, along with external conditions such as pH and ionic strength [6]. In insect studies, these bioactivities may also support the development of biocompatible insect-based materials for tissue scaffolding, biosensing, and enzymatic studies. As technological innovations in nanotechnology, entomology, and polymer chemistry converge, chitosan especially from insect sources emerges as a promising material that bridges biological understanding with applied biomaterial science. This review highlights the diverse origins of chitosan, particularly entomological and marine, and explores its key properties and expanding biopolymer applications relevant to both insect science and biomedical fields [7].

Sources of Chitosan

The origin of chitin significantly affects the yield, physicochemical characteristics, and application potential of the chitosan derived from it. Key biological sources include insects, marine crustaceans, fungi, krill, and various agricultural and industrial residues. These sources differ in terms of ecological impact, availability, allergenic potential,

and suitability for biomedical and biotechnological applications. Figure 1 shows the sources of chitosan, highlighting the diversity and relevance of each origin in chitosan production.

Insects

Insects are emerging as a sustainable and eco-friendly source of chitosan, offering advantages such as high reproduction rates, minimal space requirements, and rapid biomass accumulation. Beetles, grasshoppers, crickets, and silkworms are among the most investigated insects for chitosan extraction due to the chitin-rich composition of their exoskeletons [8]. Insect-derived chitosan exhibits comparable structural properties to crustacean-sourced chitosan and can be customized for targeted applications in drug delivery, wound healing, and biosensors [9]. Moreover, insect farming poses a lower ecological burden and may facilitate local biopolymer production, especially in regions lacking access to marine resources.

Marine Crustaceans

Crustaceans such as shrimp, crab, and lobster remain the dominant industrial source of chitosan due to the abundance of chitin in their exoskeletons, a by-product of seafood processing. Crustacean-derived chitosan is typically high in molecular weight and mechanical integrity, making it well-suited for applications such as film formation, microspheres, and controlled drug release systems [10, 11]. However, concerns over marine allergens and seasonal variability in shell availability have prompted interest in alternative sources.

Fungi

Fungal species including *Mucor rouxii* and *Aspergillus niger* serve as non-animal chitosan sources, ideal for vegetarian, kosher, and hypoallergenic formulations [12]. Fungal chitosan is typically produced through submerged fermentation, offering uniformity in composition and fewer contaminants compared to marine counterparts. This form of chitosan is gaining traction in pharmaceutical and biomedical fields due to its safety profile and regulatory acceptance [13].

Krill

Krill, small crustaceans native to cold marine environments, are another viable source of chitosan. Krill-derived chitosan generally features lower molecular weight and enhanced solubility, attributes that favor its use in injectable, mucosal, and ophthalmic drug delivery systems [14]. Despite its promising properties, environmental concerns surrounding krill harvesting, including ecosystem disruption and overfishing, limit its sustainable scalability [15].

Agricultural and Industrial Waste

Unconventional chitosan sources such as insect moltings, mushroom stems, and aquaculture residues are gaining attention for their potential in waste valorization. These materials offer a dual benefit of reducing bio-waste and generating valuable biopolymers. However, variability in raw material quality, regional availability, and the need for intensive purification pose challenges to consistent pharmaceutical-grade production [16].

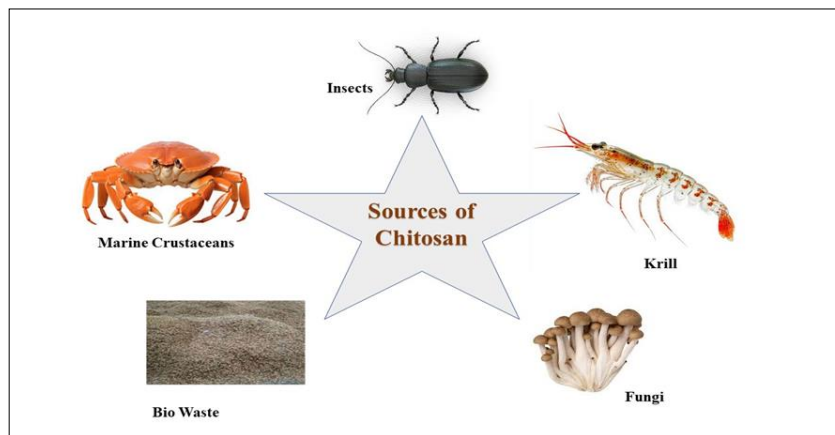


Fig 1: Sources of Chitosan

Properties of Chitosan

Chitosan exhibits a diverse range of physicochemical and biological characteristics, making it a multifunctional biopolymer with significant value in biomedical and pharmaceutical research. These properties are largely governed by parameters such as molecular weight, degree of deacetylation (DDA), and environmental factors including pH and ionic strength.

Biocompatibility and Biodegradability

Chitosan demonstrates excellent compatibility with human tissues and is safely degradable *in vivo*. It is enzymatically broken down by lysozyme and other hydrolases into non-toxic products such as glucosamine and chitooligosaccharides, which are either metabolized or excreted without harmful effects [17, 18].

Cationic Behavior and Acid Solubility

The presence of primary amine groups along its polymer chain renders chitosan a cationic biopolymer under mildly acidic conditions (pH < 6.5). This positive charge promotes electrostatic interactions with negatively charged cell membranes and therapeutic molecules, facilitating enhanced drug loading, mucoadhesion, and cellular uptake. Chitosan is readily soluble in dilute organic acids, such as acetic or lactic acid, due to the protonation of its amino groups [19].

Mucoadhesive Capability

Chitosan adheres strongly to mucosal surfaces by forming ionic bonds with sialic acid and other negatively charged moieties present in mucin. This mucoadhesiveness significantly prolongs the residence time of drug formulations in nasal, ocular, gastrointestinal, and buccal

tissues, leading to improved drug absorption and therapeutic efficacy [20,21].

Antimicrobial and Antioxidant Actions

Chitosan is known for its broad-spectrum antimicrobial efficacy, which stems from its ability to interact with and disrupt microbial cell membranes. This leads to increased membrane permeability, leakage of intracellular components, and eventual microbial death. Furthermore, chitosan and its derivatives possess free radical scavenging capabilities, making them useful in mitigating oxidative stress and associated pathological conditions [22, 23].

Film-Forming and Hydrogel Properties

Chitosan can form flexible, transparent films and hydrogels, especially when crosslinked with agents such as genipin or glutaraldehyde. These materials are useful in wound dressings, transdermal patches, and drug delivery matrices. Gelation behavior is pH-dependent and is influenced by polymer concentration, ionic strength, and the type of crosslinking used [24,25].

Chemical Functionalization

The abundant hydroxyl and amino groups in chitosan allow extensive chemical modification. Functionalization approaches, including thiolation, carboxymethylation, and quaternization, are employed to tailor its solubility, charge, degradation rate, and drug release profiles. These modifications enhance its performance in site-specific and controlled-release pharmaceutical systems [26, 27].

Hemostatic and Non-Toxic Effects

Chitosan is recognized for its hemostatic properties, which include the promotion of platelet adhesion and activation of coagulation pathways. It is also generally regarded as non-toxic, making it a safe component in wound management, surgical hemostats, and other clinical applications [28,29].

Biopolymer Applications of Chitosan

Chitosan, owing to its unique combination of biocompatibility, biodegradability, non-toxicity, mucoadhesiveness, and film-forming ability, has emerged as a multifunctional biopolymer. These properties enable chitosan to be widely applied across diverse sectors such as healthcare, agriculture, food processing, environmental management, and materials science.

Food Industry Applications

Chitosan is extensively used as a food preservative and packaging material due to its antimicrobial and antioxidant activities. It can extend shelf life, inhibit the growth of spoilage organisms, and serve as an edible coating on fruits, vegetables, and meat products. Additionally, chitosan-based films are being developed as biodegradable alternatives to synthetic plastics [30].

Agricultural Applications

In agriculture, chitosan is employed as a natural biostimulant and pesticide. It enhances plant growth by inducing systemic resistance against pathogens and improving nutrient uptake. Chitosan-based formulations are also used to encapsulate agrochemicals, enabling slow and controlled release, which minimizes environmental impact [31].

Water Treatment and Environmental Remediation

Chitosan's ability to chelate heavy metals and bind organic pollutants makes it effective in water purification systems. It is used to remove contaminants such as lead, arsenic, dyes, and pesticides from industrial wastewater. Its flocculating and adsorption capabilities have promoted its application in eco-friendly water treatment technologies [32].

Biomedical and Healthcare Applications

Chitosan continues to be a key material in healthcare due to its biocompatibility, antimicrobial activity, hemostatic ability, and capacity to support tissue regeneration. It is extensively used in wound dressings, surgical sutures, dental care products, and contact lenses. Its ability to encapsulate a wide array of drugs from small molecules to large biomacromolecules such as proteins and nucleic acids makes it ideal for drug delivery applications. Chitosan's positive charge under acidic conditions facilitates interaction with negatively charged mucosal surfaces, enhancing drug retention and absorption. It is particularly effective in improving the oral bioavailability of poorly absorbed or unstable drugs by transiently opening tight junctions and protecting them from enzymatic degradation [33,34]. For nasal and pulmonary routes, chitosan-based nanoparticles improve mucosal adhesion and systemic delivery, making them suitable for biologics and vaccines [35]. In transdermal and topical applications, chitosan's gelation and film-forming abilities enable sustained drug release and promote wound healing while providing antimicrobial protection [36]. As a non-viral vector in gene delivery, chitosan forms electrostatic complexes with nucleic acids, shielding them from enzymatic degradation and enhancing cellular uptake, with reduced immunogenicity compared to viral vectors [37]. Furthermore, chitosan exhibits intrinsic antimicrobial activity by disrupting microbial membranes, and its bioactive nature supports wound healing through fibroblast stimulation, collagen deposition, and angiogenesis, leading to advanced wound care formulations [38]. In cancer therapy, chitosan nanoparticles can be functionalized for receptor-mediated targeting of tumor cells, enabling controlled, site-specific release of chemotherapeutic agents and reducing systemic toxicity [39]. Its mucoadhesive and immunomodulatory properties also support its role as a vaccine adjuvant, enhancing antigen uptake and stimulating both humoral and cellular immune responses [40]. Due to its structural similarity to extracellular glycosaminoglycans, chitosan is also widely applied in tissue engineering and regenerative medicine, where it acts as a scaffold for artificial skin, cartilage, and bone regeneration with adjustable biodegradation rates [41].

Cosmetics and Personal Care

Chitosan exhibits moisturizing, antimicrobial, and film-forming properties beneficial in skin creams, shampoos, and conditioners. It contributes to formulation stability, skin healing, and anti-aging effects [42].

Textile and Paper Industries

Chitosan is utilized in textiles to impart antimicrobial, antistatic, and flame-retardant properties. In paper production, it enhances printability, mechanical strength, and water resistance [43].

Bioplastics and Packaging

Chitosan is increasingly used in developing biodegradable plastics. When blended with other polymers, it forms flexible, durable films ideal for sustainable packaging, reducing dependency on petroleum-based plastics^[44].

Conclusion

Chitosan, a biopolymer derived through deacetylation of chitin, presents a unique combination of biocompatibility, biodegradability, non-toxicity, and functional versatility, making it a material of immense interest across scientific domains. Insects and marine crustaceans represent two major sources, with insect-derived chitosan gaining recognition as a sustainable and ecologically responsible alternative to traditional marine sources. The comparable physicochemical characteristics of insect and marine chitosan, coupled with the growing need for scalable and allergen-free biomaterials, underscore the relevance of entomological sources in modern applications. Chitosan's cationic nature, mucoadhesiveness, and film-forming ability facilitate its wide-ranging use in pharmaceutical, agricultural, environmental, and biomedical fields, particularly in drug delivery, wound healing, and tissue engineering. Moreover, advancements in polymer modification techniques have expanded chitosan's functional landscape, enabling targeted and controlled therapeutic delivery, biosensing, and bioplastic development. As research continues to integrate principles from entomology, materials science, and nanotechnology, chitosan stands out as a bridge between sustainable resource utilization and high-performance biomaterial innovation. The shift toward insect-based chitosan not only supports environmental goals but also promotes circular bioeconomy models, positioning this biopolymer as a cornerstone for next-generation applications in healthcare and beyond.

References

1. Synowiecki J, Al-Khateeb NA. Production, properties, and some new applications of chitin and its derivatives. *Crit Rev Food Sci Nutr*,2003;43(2):145–171.
2. Rinaudo M. Chitin and chitosan: properties and applications. *Prog Polym Sci*,2006;31(7):603–632.
3. Illum L. Chitosan and its use as a pharmaceutical excipient. *Pharm Res*,1998;15(9):1326–1331.
4. Mao S, Shuai X, Unger F, Simon M, Bi D, Kissel T. The depolymerization of chitosan: effects on physicochemical and biological properties. *Int J Pharm*,2004;281(1-2):45–54.
5. Kong M, Chen XG. Antimicrobial properties of chitosan and mode of action: A state of the art review. *Int J Food Microbiol*,2015;144(1):51–63.
6. Dash M, Chiellini F, Ottenbrite RM, Chiellini E. Chitosan—a versatile semi-synthetic polymer in biomedical applications. *Prog Polym Sci*,2011;36(8):981–1014.
7. Ahmed S, Ikram S. Chitosan and its derivatives: A review in recent innovations. *Int J Pharm Pharm Sci*,2015;7(2):36–41.
8. Kaya M, Baran T, Erdoğan S, *et al.* Physicochemical characterization of chitin and chitosan obtained from various insects. *Int J Biol Macromol*,2014;65:553–558.
9. Muzzarelli RAA. Chitins and chitosans for the repair of wounded skin, nerve, cartilage and bone. *Carbohydr Polym*,2009;76(2):167–182.
10. No HK, Meyers SP. Preparation and characterization of chitin and chitosan—a review. *J Aquat Food Prod Technol*,1995;4(2):27–52.
11. Shahidi F, Abuzaytoun R. Chitin, chitosan, and co-products: chemistry, production, applications, and health effects. *Adv Food Nutr Res*,2005;49:93–135.
12. Pochanavanich P, Suntornsuk W. Fungal chitosan production and its characterization. *LWT - Food Sci Technol*,2002;35(6):521–526.
13. Jayakumar R, Prabakaran M, Sudheesh Kumar PT, Nair SV, Tamura H. Biomaterials based on chitin and chitosan in wound dressing applications. *Biotechnol Adv*,2011;29(3):322–337.
14. Ngo DH, Kim SK. Chitin and chitosan from krill. *Mar Drugs*,2014;12(11):5384–5406.
15. Nicol S, Foster J. The fishery for Antarctic krill: its current status and management regime. *Fish Fish*,2003;4(2):146–174.
16. Yen MT, Yang JH, Mau JL. Antioxidant properties of chitin and chitosan from shiitake stipes. *Food Res Int*,2008;41(9):961–968.
17. Dash M, Chiellini F, Ottenbrite RM, Chiellini E. Chitosan—A versatile semi-synthetic polymer in biomedical applications. *Prog Polym Sci*,2011;36(8):981–1014.
18. Kean T, Thanou M. Biodegradation, biodistribution and toxicity of chitosan. *Adv Drug Deliv Rev*,2010;62(1):3–11.
19. Thanou M, Verhoef JC, Junginger HE. Oral drug absorption enhancement by chitosan and its derivatives. *Adv Drug Deliv Rev*,2001;52(2):117–26.
20. Bernkop-Schnürch A, Dünhaupt S. Chitosan-based drug delivery systems. *Eur J Pharm Biopharm*,2012;81(3):463–9.
21. Lehr CM, Bouwstra JA, Schacht EH, Junginger HE. *In vitro* evaluation of mucoadhesive properties of chitosan and some other natural polymers. *Int J Pharm*,1992;78(1-3):43–8.
22. Goy RC, de Britto D, Assis OB. A review of the antimicrobial activity of chitosan. *Polímeros*,2009;19(3):241–7.
23. Park PJ, Je JY, Kim SK. Free radical scavenging activity of chitoooligosaccharides by electron spin resonance spectrometry. *J Agric Food Chem*,2003;51(16):4624–7.
24. Berger J, Reist M, Mayer JM, Felt O, Peppas NA, Gurny R. Structure and interactions in covalently and ionically crosslinked chitosan hydrogels for biomedical applications. *Eur J Pharm Biopharm*,2004;57(1):19–34.
25. Kumar MNVR. A review of chitin and chitosan applications. *React Funct Polym*,2000;46(1):1–27.
26. Jayakumar R, Prabakaran M, Nair SV, Tokura S, Tamura H, Selvamurugan N. Novel carboxymethyl derivatives of chitin and chitosan materials and their biomedical applications. *Prog Mater Sci*,2010;55(7):675–709.
27. Kean T, Thanou M. Biodegradation, biodistribution and toxicity of chitosan. *Adv Drug Deliv Rev*,2010;62(1):3–11.
28. Cho YW, Chung SH, Yoo G, Ko SW. Water-soluble chitosan as a wound healing accelerator. *Biomaterials*,1999;20(22):2139–45.
29. Klokkevold PR, Vandemark L, Kenney EB, Bernick S. Effect of chitosan on lingual hemostasis in rabbits. *J Oral Maxillofac Surg*,1999;57(1):49–52.

30. Kong M, Chen XG. Antimicrobial properties of chitosan and mode of action: A state of the art review. *Int J Food Microbiol*,2015;144(1):51–63.
31. Malerba M, Cerana R. Chitosan effects on plant systems. *Int J Mol Sci*,2016;17(7):996.
32. Rinaudo M. Chitin and chitosan: Properties and applications. *Prog Polym Sci*,2006;31(7):603–632.
33. Dash M, Chiellini F, Ottenbrite RM, Chiellini E. Chitosan—a versatile semi-synthetic polymer in biomedical applications. *Prog Polym Sci*,2011;36(8):981–1014.
34. Smith AM, Woodrow KA. Oral delivery of macromolecular drugs using chitosan-based nanocarriers: A review. *Drug Deliv Transl Res*,2021;11(4):1231–1250.
35. Patel MM, Patel BM. Crossing the barrier: Nasal delivery systems for vaccine and drug delivery. *J Drug Target*,2020;28(2):113–130.
36. Zhao X, Guo B, Wu H, Liang Y, Ma PX. Injectable antibacterial conductive hydrogels with dual response to an electric field and pH for localized drug delivery and wound healing. *Acta Biomater*,2019;95:154–166.
37. Li W, Deng J, Pan X, Zhang X, Liu J. Chitosan-based gene delivery systems: Progress and challenges. *Int J Biol Macromol*,2019;131:298–310.
38. Chen XG, Park HJ. Chemical characteristics of chitosan influencing antimicrobial activity. *J Agric Food Chem*,2003;51(6):2003–2008.
39. Miao X, Wang Y, Yang Y, Shen Y, Li W. Stimuli-responsive chitosan-based nanoparticles for controlled drug delivery. *Pharmaceutics*,2021;13(2):238.
40. Illum L. Chitosan and its use as a vaccine adjuvant. *Expert Rev Vaccines*,2016;15(7):853–869.
41. Jayakumar R, Prabakaran M, Sudheesh Kumar PT, Nair SV, Tamura H. Biomaterials based on chitin and chitosan in wound dressing applications. *Biotechnol Adv*,2011;29(3):322–337.
42. Muzzarelli RAA. Cosmetic properties of chitosan and its derivatives. In: *Chitin and Chitosan for Regenerative Medicine*. Springer, 2015, 419–426.
43. Singla AK, Chawla M. Chitosan: Some pharmaceutical and biological aspects—An update. *J Pharm Pharmacol*,2001;53(8):1047–1067.
44. Aranaz I, Harris R, Heras A. Chitosan amphiphilic derivatives. Chemistry and applications. *Curr Org Chem*,2010;14(3):308–330.