RESEARCH ARTICLE

Application of Chitosan in Industry and Medicine: A Mini-Review

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Funding: No specific funding was received for this work.

Potential competing interests: No potential competing interests to declare.

Abstract

Chitosan, a biopolymer derived from chitin, has attracted considerable attention due to its versatile applications in industry and medicine. In industry, chitosan is used due to its remarkable properties such as biodegradability, biocompatibility and antimicrobial activity. It is used in various sectors including wastewater treatment, food packaging and fabric production. In medicine, the unique properties of chitosan make it a valuable material for drug delivery systems, wound healing, tissue engineering, etc. Its biocompatibility and ability to enhance drug absorption make it a promising candidate for pharmaceutical applications. The multifaceted nature of chitosan offers a wide range of opportunities for innovative developments in industrial and medical fields.

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Keyword: chitin, chitosan, medicine, biodegradability, biocompatibility.

Introduction

Chitosan, a derivative of chitin that is abundantly found in the exoskeleton of crustaceans and insects, has attracted considerable attention due to its diverse applications in industrial and medical fields [1]. This introduction deals with the versatile nature of chitosan and its central role in industry and medicine. In industry, chitosan exhibits remarkable properties that make it a valuable material in various sectors [2]. Biocompatibility, biodegradability, antimicrobial properties and high absorption capacity have made it an important component in water treatment, agriculture, food and beverage, cosmetics and textiles [3]. The distinctive properties of chitosan play a key role in enhancing processes related to water treatment, agricultural sustainability, food preservation, cosmetic formulations, and environmentally friendly textile production methods [4]. In the medical field, chitosan's biocompatible nature, non-toxicity, and wound healing properties have attracted considerable interest in the biomedical field [5]. Chitosan-based materials are very important in medical applications such as drug delivery systems, tissue engineering, wound care and regenerative medicine [6]. Its versatility in drug delivery allows for the targeted release of drugs, while its scaffold structures promote tissue regeneration and wound healing. The hemostatic and antibacterial properties of chitosan wound dressings help in effective wound management and healing processes [7]. The diverse application of chitosan in industrial and medical fields emphasizes its potential to tackle a wide range of challenges and contribute to sustainable practices [8]. Through innovative applications and ongoing research, chitosan continues to pave the way for advancements in industry and healthcare and it provides an environmentally friendly, environmentally friendly and functional solution with extensive possibilities for future developments and applications {m/9/}.

History of chitosan in industry and medicine

Chitosan, a biopolymer derived from chitin, has a rich history of use in industry and medicine. First discovered in the 19th century, chitosan gained popularity in the mid-20th century when its unique properties were recognized for industrial applications [9]. In industry, chitosan found primary use in water treatment due to its ability to bind to heavy metals and other pollutants and facilitate their removal from wastewater [10]. Over time, its applications expanded to include food preservation, textile production, and cosmetics due to its biodegradation and antimicrobial properties. In medicine, the history of chitosan dates back to the 1970s, when researchers began exploring its potential in biomedical applications [11]. The biocompatibility and non-toxic nature of chitosan make it an attractive material for wound healing and tissue engineering. As research progressed, the role of chitosan expanded to drug delivery systems, where its ability to enhance drug absorption and release characteristics became a focal point for pharmaceutical applications [12]. Today, the history of chitosan in industry and medicine reflects a journey of discovery and innovation that shows its evolution from a natural biopolymer to a multifaceted material with diverse applications in various sectors [13].

Characteristics of chitosan in industry and medicine

Chitosan, a biopolymer derived from chitin, exhibits unique properties that make it a valuable material in industrial and medical applications:

In industries

1. **Biodegradability**: Chitosan is biodegradable, making it environmentally friendly and suitable for various industrial processes without causing long-term damage to the ecosystem [14].
2. **Antimicrobial properties**: The inherent antimicrobial activity of chitosan allows it to be used in products such as food packaging and textiles to prevent the growth of bacteria and fungi [15].
3. **Absorption capacity**: Chitosan has a high absorption capacity for heavy metals and organic compounds, which makes it effective in water purification processes to remove pollutants [12].

In medicine

1. **Biocompatibility**: Chitosan is biocompatible, meaning it is well tolerated by the human body, so it is suitable for medical applications such as wound dressings and tissue engineering [12].
2. **Increased drug delivery**: Chitosan can increase drug absorption due to its mucoadhesive properties, making it a promising material for drug delivery systems that require controlled release of drugs [12].
3. **Wound healing properties**: Chitosan improves wound healing by creating a protective barrier against infections, stimulating tissue regeneration and reducing inflammation.

These features highlight the versatility of chitosan in industry and medicine and show its potential for innovative developments in various fields [12].

How to produce chitosan in industry and medicine?

Industrial production

1. **Material source**: Chitosan is derived from chitin, a natural polymer found in the shell of crustaceans such as shrimp, crab and lobster, as well as in the cell wall of fungi. The first step in production involves sourcing chitin-rich waste materials from seafood processing industries or mushrooms [14].
2. **Dematerialization of chitin**: Chitin-rich raw materials undergo demineralization and deproteinization processes to remove calcium carbonate and proteins, leaving a chitin-rich matrix behind [12].
3. **Deacetylation**: The chitin matrix undergoes deacetylation using alkaline hydrolysis, and by removing acetyl groups and increasing amino groups, chitin is converted into chitosan, resulting in a polymer with more positive charge sites [16].
4. **Purification**: The resulting chitosan is then purified through processes such as filtration, sedimentation and drying to obtain a high quality chitosan product with desirable characteristics for industrial applications [17].

Medical production

1. **Medical Grade Chitosan:** For medical applications, the production of chitosan must follow strict quality standards to ensure biocompatibility and safety for human use. Medical grade chitosan is manufactured according to Good Manufacturing Practices (GMP) [12].
2. **Biomedical applications**: Chitosan for medical use undergoes further processing steps to meet specific requirements for drug delivery systems, wound dressings, tissue engineering scaffolds and other biomedical applications [17].
3. **Sterilization**: Medical grade chitosan is sterilized using methods such as gamma irradiation, ethylene oxide treatment, or autoclaving to ensure sterility and safety for medical procedures [18].
4. **Formulation**: Pharmaceutical companies and medical device manufacturers use medical grade chitosan to produce formulations for targeted drug delivery, wound healing products, regenerative medicine and other healthcare applications [19].

Quality control

1. **Identification**: Industrial and medical chitosan are characterized through techniques such as Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), scanning electron microscopy (SEM) and gel permeation chromatography (GPC) to evaluate their purity and properties [20].
2. **Batch consistency**: Strict quality control measures are implemented from batch to batch to ensure the consistency, purity and safety of chitosan products for industrial and medical use [21].
3. **Compliance with regulations**: The production of medical grade chitosan for medicine complies with the guidelines and standards set by health authorities to ensure the safety and efficacy of chitosan-based medical products [14].

In summary, the production of chitosan for industrial and medical applications involves the supply of chitin-rich materials, demineralization, deacetylation, purification and specific processing steps that meet the quality requirements of the intended applications in industries and healthcare. Quality control and compliance with regulatory standards are critical aspects of chitosan production to ensure its performance and safety in various industrial and medical environments.

Applications of chitosan in industries

Water purification

Chitosan is widely used in water purification due to its exceptional properties. Applications of chitosan in water purification include:

1. **Absorption of heavy metals**: Chitosan-based materials are used to remove heavy metals such as lead, copper, chromium, cobalt, and mercury from water sources due to their high absorption capacity [22].
2. **Removal of organic and inorganic pollutants**: Chitosan composites are effective in removing various organic and inorganic pollutants such as dyes (methylene blue), antibiotics (ofloxacin), phenol and oil from water systems and improve the quality Water helps [23].

3. **Improved water treatment performance**: Chitosan-based hydrogels are known for their bioavailability, biocompatibility, biodegradability and high pollutant adsorption capacity, which makes them ideal for water treatment applications [24].
4. **Incorporation of nanomaterials**: Nanomaterials such as nanoparticles, graphene, and metal-organic frameworks are incorporated into chitosan-based hydrogels to enhance their performance in water treatment by improving absorption, filtration, and antimicrobial activity [15].

These applications highlight the important role of chitosan in water treatment processes and demonstrate its effectiveness in dealing with global water pollution challenges.

Food packing

Types of application of chitosan in food packaging are:

1. **Antibacterial properties**: Chitosan is used in food packaging due to its antibacterial activity and helps to prevent the growth of bacteria and increase the shelf life of packaged food products [25].
2. **Antioxidant properties**: Chitosan-based nanocomposite films have been developed for food packaging applications due to their antioxidant properties that help preserve the quality and freshness of packaged foods [26].
3. **Increasing food preservation**: The bioactive properties of chitosan, such as antibacterial and antioxidant activities, make it an effective material for increasing the preservation of food in packaging, thereby improving the shelf life and quality of perishable foods [27].

These applications highlight the important role of chitosan in food packaging and demonstrate its potential to enhance food safety and quality through innovative packaging solutions.

Textile production

Chitosan, a versatile material, finds various applications in textile production, as indicated in the references provided:

1. **Biocompatible property**: The biocompatible nature of chitosan makes it promising for application in textiles and offers advantages such as increased biocompatibility and absorbability [28].
2. **Functional textile structures**: When chitosan is incorporated into textile fibers, it creates properties such as structure capacity, layering systems and antimicrobial activity, and increases the performance of textile products [29].
3. **Challenges and concerns**: Despite its potential, there are challenges in the application of chitosan in textiles, including market recognition, differences between chitosan and chitin fibers, antibacterial post-treatment, testing standards, and user understanding, which must be addressed for success. This insight sheds light on the diverse applications of chitosan in textile production and emphasizes its role in enhancing textile performance and addressing industry challenges [30].

Cosmetic

The uses of chitosan in cosmetic products include:

1. **Antimicrobial and restorative properties**: Due to its antimicrobial and restorative properties, chitosan is used in cosmetic formulations for dental and oral applications and helps to develop functional cosmetic products for oral hygiene [31].
2. **Advanced cosmetic formulations**: Chitosan is included in emulsions as examples of advanced cosmetic formulations and shows its versatility in creating innovative cosmetic products with beneficial properties for skin care [32].
3. **Biodegradability and bioactivity**: The biodegradability, non-toxicity, biocompatibility and bioactivity of chitosan make it a valuable ingredient in contemporary cosmetic production with benefits for skin, hair, nail and oral care products [33].

These applications demonstrate the diverse applications of chitosan in cosmetology and highlight its potential to enhance the efficacy and performance of cosmetic products in various categories.

Plant protection

Chitosan, a natural biopolymer, offers a variety of applications in plant protection, as shown in the following references:

1. **Antifungal, antibacterial and antiviral properties**: Chitosan nanoparticles have antifungal, antibacterial and antiviral properties and effectively fight pathogens in seeds and soil in plants [34].
2. **Induction of defense responses**: Chitosan acts as an effective molecule and induces local and systemic defense responses in plants, thereby increasing their resistance to pathogens and promoting overall plant health [35].
3. **Enhancement of host plant defense**: Chitin and chitosan fragments induce various defense reactions in host plants, such as the accumulation of phytoalexins, pathogen-related proteins, and lignin synthesis, which help to enhance plant defense against diseases [36].
4. **Biological methods in agriculture**: Chitosan-based materials offer biological alternatives to chemical products in agriculture, providing safe and cost-effective solutions to protect plants, increase productivity and extend the commercial life of fruits [37].

These applications emphasize the important role of chitosan in plant protection and demonstrate its potential to revolutionize agricultural practices and promote sustainable management of agricultural products.

Applications of chitosan in medicine

Drug

Types of applications of chitosan in drug delivery include:

1. **Drug delivery systems based on nanomaterials:** Nanomaterials derived from chitosan are widely used in drug

delivery systems and play an important role in pharmaceutical, medical, biological and other sectors. These nanomaterials provide new drug delivery systems with applications in various fields including industry, biology and medicine [38].

2. **Increase in drug absorption and release**: Chitosan-based drug delivery systems have been designed to enhance drug absorption and achieve controlled release of drugs, making them valuable for targeted and sustained drug delivery in various administration routes such as oral, ocular, transdermal, nasal, and vaginal [39].
3. **Cancer treatment**: Chitosan has multifaceted applications in cancer treatment, aiding in gene transfer, chemotherapy delivery, and as an immunoadjuvant for vaccines. Its biocompatible and biodegradable nature makes it a versatile material for drug delivery and therapy in the field of cancer treatment [40].

These applications highlight the diverse and significant role of chitosan in drug delivery systems and demonstrate its potential to revolutionize drug administration and improve therapeutic outcomes in various medical fields.

Wound dressing

The applications of chitosan in wound dressing are:

1. **Biocompatible and biodegradable hydrogels**: Chitosan-based hydrogels are used in wound dressing applications due to their biocompatibility and biodegradability, and provide a safe and effective solution for wound care [41].
2. **Nanofibrous scaffolds**: Chitosan nanofibrous scaffolds, containing tannic acid and metal-organic frameworks, have been developed for hemostatic wound dressing applications, demonstrating the versatility of chitosan in promoting wound healing and homeostasis [42].
3. **Composite films**: Chitosan/gelatin/nanocrystalline cellulose/calcium peroxide composite films are prepared and characterized for potential wound dressing applications, highlighting the development of advanced wound care materials with enhanced properties for effective wound management [43].
4. **Chitosan membranes**: Chitosan membranes fabricated using non-toxic cross-linkers have been designed for wound dressing applications, demonstrating the versatility of chitosan-based materials in creating wound dressings with optimal properties to improve tissue healing and regeneration [44].
5. **Biomaterials for wound dressing**: Biomaterials based on chitin and chitosan are widely used in wound dressing applications, emphasizing their role in providing effective and biocompatible solutions for wound care [45].

These applications highlight the diverse applications of chitosan in wound dressings and demonstrate its potential to revolutionize wound care practices and improve patient outcomes in healthcare.

Tissue engineering

Chitosan, a versatile biopolymer, finds various applications in tissue engineering, as highlighted in the references provided:

1. **Bone regeneration**: Chitosan-based materials are used in bone regeneration applications and show their potential to

promote bone tissue growth and repair in regenerative medicine [46].

2. **Cartilage tissue regeneration**: Chitosan and its derivatives play a role in cartilage tissue regeneration and provide biocompatible and biodegradable solutions for repairing damaged cartilage in tissue engineering applications [47].
3. **Cardiac tissue regeneration**: Chitosan biomaterials are used in cardiac tissue regeneration and show their ability to support the growth and repair of cardiac tissues for potential applications in cardiovascular regenerative medicine [48].
4. **Corneal regeneration**: Chitosan-based materials aid corneal regeneration efforts and provide biocompatible and bioactive solutions to promote corneal tissue repair and regeneration in tissue engineering applications [49].
5. **Periodontal tissue regeneration**: Chitosan is used in periodontal tissue regeneration and offers benefits to promote the growth and repair of periodontal tissues in restorative medicine approaches [50].

These applications emphasize the diverse applications of chitosan in tissue engineering and highlight its potential to drive advances in regenerative medicine and improve outcomes in various biomedical fields.

Hemostasis (blood clotting)

Chitosan has various uses in hemostasis (blood clotting) as evidenced in the following sources:

1. **Skin homeostasis**: Chitosan-based nanocomposites, along with rectorite clay, have been developed for skin homeostasis applications. These injectable nanocomposites have hemostatic properties, reduce clotting time, and effectively adhere to the skin to prevent bleeding, showing potential to promote hemostasis in skin injuries [51].
2. **Effects on blood coagulation**: Studies have shown that chitosan and its derivative carboxymethyl chitosan (CMC) can interact with blood components and affect the structure and function of proteins related to clotting such as fibrinogen. The presence of chitosan and CMC alters the structure and composition of fibrinogen and affects the coagulation process by altering thromboelastography (TEG) parameters, providing valuable insights into the molecular basis for the biological response to chitosan in blood coagulation [52].

These applications highlight the role of chitosan in promoting hemostasis and blood coagulation and demonstrate its potential to address bleeding issues and enhance wound healing processes.

Gene therapy

Applications of chitosan in gene therapy include:

1. **Gene delivery**: Chitosan and its derivatives are used as non-viral carrier systems for gene delivery in gene therapy. Biocompatibility, biodegradability, structural integrity and stability make them ideal carriers for gene transfer to target cells for the treatment of genetic disorders and cancer [53].
2. **Structural modification**: Chitosan's amenability to structural modification allows it to serve as an effective carrier for controlled drug delivery in gene therapy applications. The non-toxicity and high biodegradability of chitosan derivatives make them promising candidates for the delivery of therapeutic genes in a controlled manner [54].
3. **Cancer treatment**: Chitosan and its derivatives have received attention in the last decade due to their applications in

cancer treatment and act as carriers for gene delivery and chemotherapy delivery. Their versatility in aiding gene delivery, immunoadjuvants for vaccines, and controlled drug release highlights their potential in cancer therapy [55].

Conclusion

From crustacean waste to a valuable material, chitosan has opened the doors to a world of possibilities in industry and medicine. Its unique combination of biocompatible, biodegradable and non-toxic properties makes it a game changer. In industry, chitosan addresses challenges related to wastewater treatment, food processing, and textiles, promoting sustainability and innovation. In medicine, chitosan is emerging as a champion in drug delivery, wound healing, and tissue engineering, offering hope for improved treatments and patient outcomes. As research deepens, the potential of chitosan continues to expand, and its possibilities extend into areas such as gene therapy and artificial organs. While some challenges remain in terms of fine-tuning properties and quality assurance, the future of chitosan is undeniably bright. This versatile biomaterial holds the promise of revolutionizing various industrial practices and medical treatments and shaping a more sustainable and healthy future.

Acknowledgments

The authors thank the Research Committee of Shahid Beheshti University and University of Kashan for financial support of this work.

{r/9/ Dehghani, A., Ghezelsofloo, M., and S. Ghasemi, S. Coupling reaction of aryl halides with phenylboronic acid using chitosan-copper (II) complex extracted from Persian Gulf shrimp shell. Applied Chemistry Today, 2024, 19(70): p. 9-28. /}

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