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Chitin and Chitosan: Versatile Biopolymers with Diverse Applications

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Abstract: Chitosan, a polysaccharide derived from the abundant natural polymer chitin, has emerged as a versatile biopolymer with diverse applications. Its unique properties, biocompatibility, biodegradability, and functional qualities have garnered significant attention since the 1970s. Chitosan has been applied in various industries, including food, paper, textiles, pharmaceuticals, medicine, cosmetics, and chemistry, with recent interest in agrochemistry, aquaculture, dentistry, ophthalmology, biomedicine, bioimaging, and other fields. The expanding markets of cosmeceuticals and nutraceuticals highlight chitosan's potential for development in therapeutic and biomedical products. This overview showcases a selection of publications on chitosan applications from the last 20 years, demonstrating its versatility and potential for future research and development. Chitosan's renewable and biodegradable nature makes it an attractive resource for sustainable applications. Its potential in agrochemistry, aquaculture, and biomedicine is particularly promising, with opportunities for the development of innovative products and technologies. As research continues to uncover the properties and applications of chitosan, its potential for future growth and development is vast.

Key words: Applications, Biopolymer, Chitin, Chitosan

1.0 Introduction

Chitin, a naturally occurring polysaccharide, forms organized macrofibrils and serves as the primary structural component of crustaceans', crabs', and shrimps' exoskeletons, as well as fungi's cell walls. For biological applications, chitin is typically converted into its deacetylated derivative, chitosan (Elieh-Ali-Komi et al., 2016). Since Henri Braconnot, a French chemist, first extracted and described chitin (C8H13O5N)n from mushrooms in 1811, it has been recognized as the second most abundant natural biopolymer worldwide (Park et al., 2010). The increasing population and food production result in rising waste generation, with a significant amount of by-products remaining unutilized despite containing valuable materials. The proper disposal of food waste is a significant challenge for industries and society during food processing. Annually, ocean living organisms produce between 1012 and 1014 tonnes of chitin, with freshwater arthropods generating 2.8 x 1010 kg and marine species producing 1.3 x 1012 kg (Yadav et al., 2019). If commercial processes were developed for extracting commercially viable polymers, this vast amount of chitin would provide sufficient raw material. However, exoskeletons are discarded as biowaste, with 45-55% of raw prawns being wasted during processing stages, and a significant portion of the exoskeleton's weight comprising chitin compounds, resulting in a substantial annual waste of chitin and shells (Reshad et al., 2021).

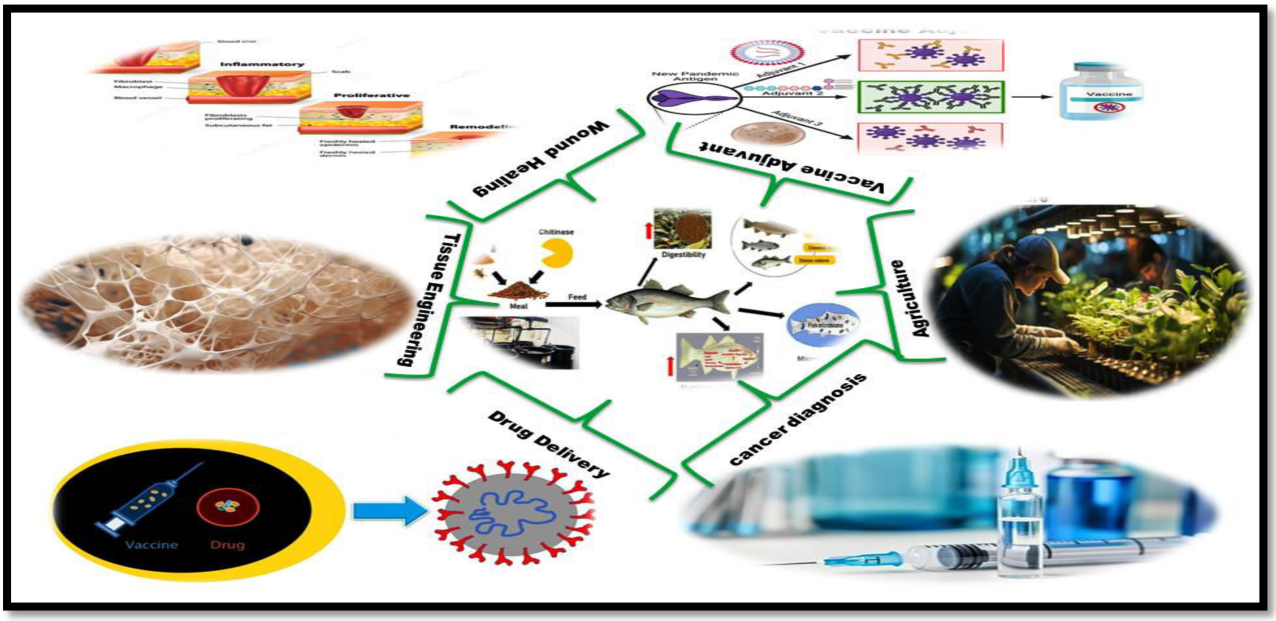

Fig.01 Schematic Representation of Chitin Applications

1.1 Structure of Chitin

Chitin's structure consists of poly-(1-4)-β-linked N-acetyl-D-glucosamine, with individual sugar units rotated 180° relative to each other, forming disaccharide N,N'-diacetyl chitobiose [(GlcNAc)2] pairs. The polymer chains have an inverted sugar unit arrangement, creating helices that contribute to high stability due to hydrogen bonding (06-H→07 and 03-H→05). Chitin has three crystalline allomorphs (α, β, and γ) with varying micro-fibril orientations, with α-chitin being the most common form. Its unit cell consists of two antiparallel chains of N,N'-diacetylchitobiose units, linked by 06-H→06 and 07→H-N hydrogen bonds between neighboring polymer chains, which run in opposite directions and are maintained in sheets Elieh-Ali-Komi et al. (2016).

1.2 Sources of Chitin

The primary sources of chitin are crustacean cuticles, particularly those from crabs and prawns, which are used to extract chitin for various applications (Younes et al., 2014). Chitin is a key component of the protein network in crustacean shells, where it provides a scaffold for calcium carbonate deposition, forming the rigid shell structure Rinaudo & Younes (2015)Additionally, chitin has been found in other organisms, including fungi such as Agaricus acris, Agaricus cantarellus, and Boletus viscidus, as well as in the epidermis and eyes of some arthropods and cephalopods, where it is present in iridophores.Braconnot, M. H. (1811)Fig.02.Interestingly research has also shown that some vertebrates, such as the fish Paralipophrys trigloides, can produce chitin in their epidermal cuticle Khousab F, Yamabhai M.,2010. The discovery of chitin in fungi was made possible through experiments involving species like Agaricus volvaceus, Acris cantarellus, and Hydnum repandum, among others Abdel-Gawad, A. M., & El-Naggar, M. E. (2017).

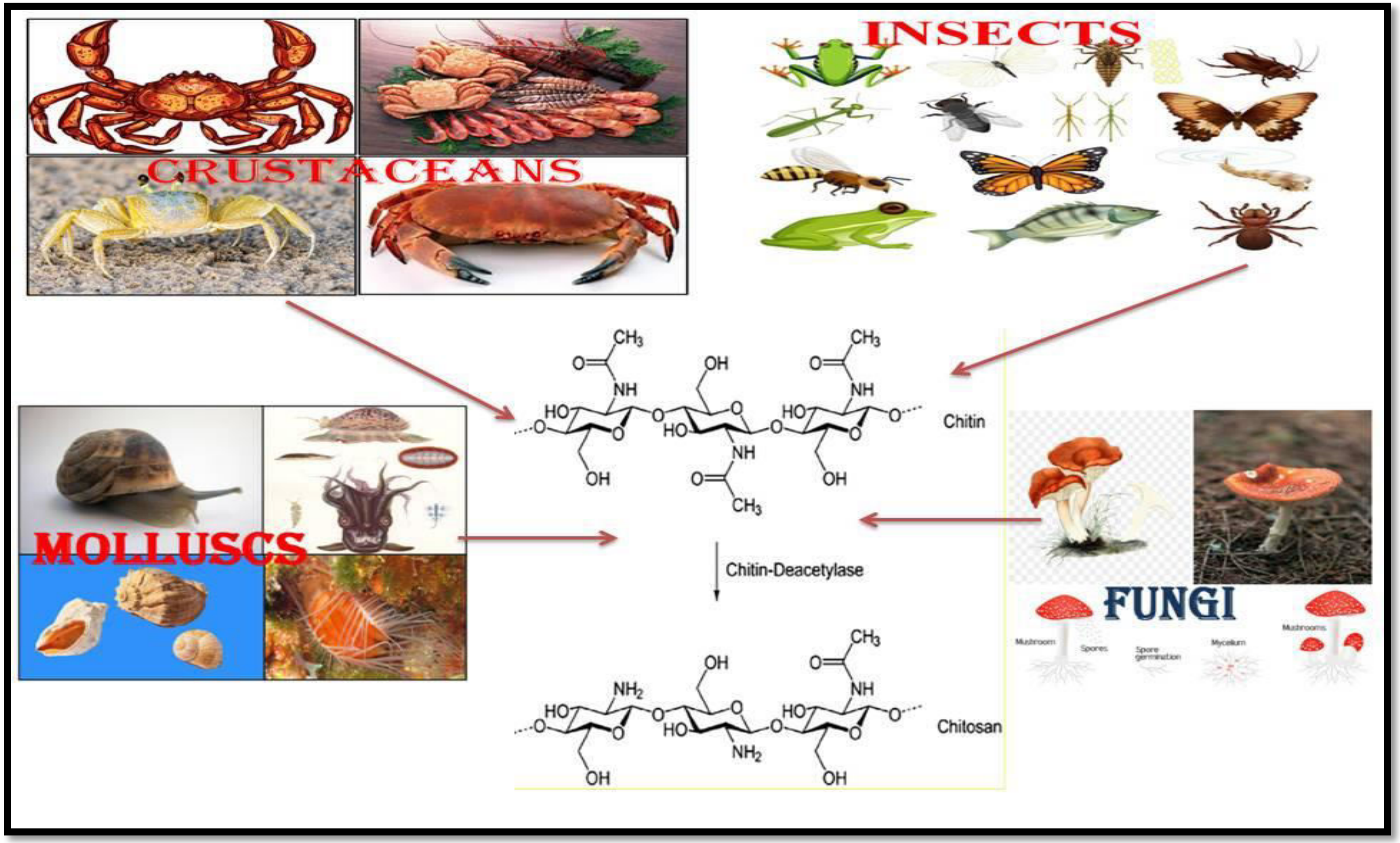

Fig. 02 Sources of chitin and chitin for various applications

Sources of Chitin: Shrimp shells**,** Crab shells**,** Lobster shells**,** Crawfish shells**,** Fish bones**,** Squid pen**,** Cell walls of fungi (e.g. Aspergillus, Penicillium)**,** Exoskeletons of insects (e.g. beetles, grasshoppers).

2.0 Chitin and its derivatives have various applications in biotechnology and industries, including:

1) **Biomedical applications and Pharmaceutical applications:** Chitin and its derivatives have been explored for their potential in wound healing, tissue engineering, and drug delivery (Elieh-Ali-Komi et al., 2016) ; (Khousab et al., 2010).
2) **Food industry:** Chitin and chitosan are used as food additives, texture modifiers, and stabilizers (Rinaudo, 2006).
3) **Cosmetics:** Chitin and chitosan are used in skincare products for their moisturizing and antimicrobial properties (Lee et al., 2015).
4) **Environmental applications:** Chitin and chitosan have been explored for their potential in heavy metal removal and wastewater treatment (Abdel-Gawad et al., 2017: (Wang et al., 2020).
5) **Agriculture:** Plant growth promoters, Soil amendments (fertilizers, pesticides),Animal feed additives.
6) **Nanotechnology:** Nanoparticles for drug delivery, Nanofibers for tissue engineering.
7) **Dental Applications:** Dental implants and prosthetics, Toothpaste and mouthwash additives.
8) **Veterinary Medicine:** Animal wound healing and tissue repair, Veterinary drug delivery systems.

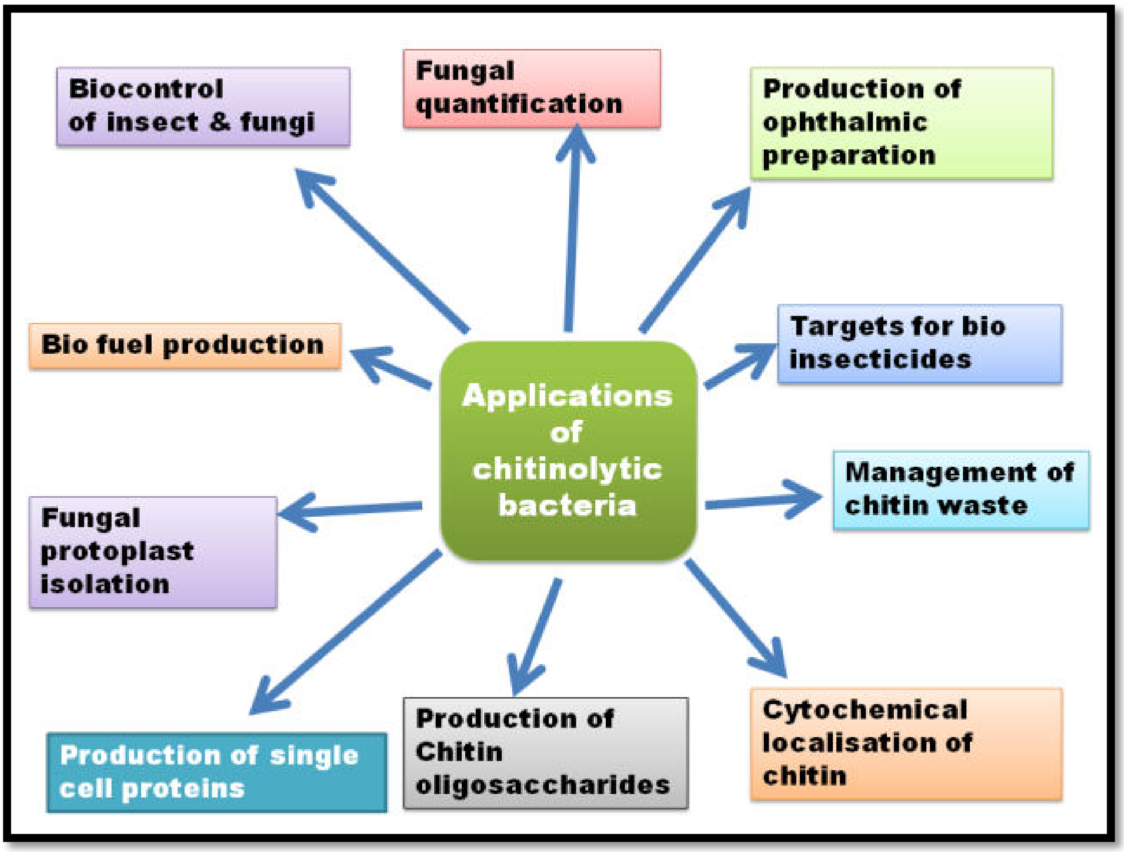

Fig.03 Chitin and its derivatives have various applications in biotechnology

Chitin various application: Chitin's biocompatibility, biodegradability, and antimicrobial properties make it a valuable resource for various industries, including pharmaceuticals, cosmetics, and agriculture.

3.0Chitin and Chitosan in Pharmaceutical Applications:

Chitosan has a spacious variety of potential uses in medicine and biology. These include drug delivery, pharmaceutical formulation, antimicrobial applications, gene delivery, gene therapy, wound healing, regenerative medicine, tissue engineering, cancer treatment, dermatology, ophthalmology, biosensors, bioimaging, support for immobilised enzymes, and veterinary medicine (Morin-Crini, Nadia, et al., 2019).

3.1 Wound healing

Chitin and chitosan have been shown to accelerate the wound-healing process. numerous studies have demonstrated their effectiveness in promoting wound healing in both clinical and veterinary settings, leading to the development of various products for wound treatment (Meszana, 2008). These products come in various forms, including sponges, granules, filaments, powders, and composites with cotton or polyester.

Chitin threads and non-woven fabrics have proven to be biodegradable, biocompatible, and effective in promoting wound healing when used as artificial skins and sutures. The primary biochemical processes involved in wound healing using chitin and chitosan-based materials include polymorphonuclear cell activation, fibroblast activation, cytokine generation, giant cell migration, and stimulation of type IV collagen synthesis (Meszana, 2008).

Research has consistently shown that chitin is a valuable material for wound treatment, with studies aiming to utilize chitin in wound dressings on a larger scale. Chitin treatment has been shown to significantly reduce treatment duration (Dung et al., 2000). Vinachitin, a chitin membrane made from decrystallized ricefield crab shells, has been developed and tested in a clinical trial with 300 patients, demonstrating its effectiveness in treating deep burns, orthopedic injuries, trauma, and ulcer diseases (Dung et al., 2000). Additionally, Ohshima et al. evaluated the use of chitin non-woven fabric for dressing skin abrasions, burns, ulcers, donor sites, and skin graft locations in 91 patients, finding that chitin dressing provided adequate pain relief, adhered well to the wound, and dried without dissolving or causing anyadverse effects.

3.2 Tissue Engineering

One crucial component of tissue engineering is the creation of polymeric scaffolds that mimic the original extracellular matrix (ECM) in terms of mechanical and biological characteristics, in order to modify cellular behavior (Agarwal et al., 2008). Chitin/chitosan nanofibers have found widespread application in tissue engineering due to their structural similarity to glycosaminoglycans in the extracellular matrix (Suh et al., 2000). Their structural characteristics are also comparable to those of fibrous collagen structures in the extracellular matrix on a nanoscale. Recent applications have demonstrated the amazing potential of chitinand chitosan nanofibers in tissue engineering (Kim et al., 2008). Current therapies for cartilage tissue injury, such as autologous chondrocyte injections, mosaicplasty, and microfracture, differ in structural makeup from native cartilage (Kock et al., 2012). Therefore, tissue engineering technology has emerged as a promising alternative for the restoration of articular cartilage. Chitosan has been used in cartilage tissue engineering applications in various forms, including fibers, sponges, and hydrogels (Muxika et al., 2017; Shariatinia et al., 2018; Domalik-Pyzik et al., 2019).

3.3 Drug delivery

Chitosan's potential in drug delivery systems is one of its most promising and encouraging features. Drug delivery refers to the safe and targeted method of delivering pharmaceutical molecules to achieve the intended therapeutic effect within the body, made possible by nanotechnology and the use of nanoparticles or combination techniques (Park et al., 2013). Chitosan is considered a valuable material for drug delivery due to its unique properties, including its cationic character, which enables it to bind to negatively charged biological surfaces (He et al., 1998). As a biocompatible and biodegradable biopolymer, chitosan has been widely employed in the pharmaceutical industry, making it an attractive candidate for use as a drug delivery carrier (Naskar et al., 2019).

Additionally, chitosan has been explored as a vaccine adjuvant, with research demonstrating its ability to enhance antibody responses to antigens (McNeela et al., 2000). Studies in humans and animal models have shown promising results, including a live-virus challenge study in ferrets, which demonstrated the effectiveness of chitosan as an adjuvant for an inactivated influenza subunit antigen (Mann et al., 2014; Yusof et al., 2001).

3.4 Vaccine Adjuvant

Research has demonstrated that intranasal chitosan glutamate can significantly enhance antibody responses to diphtheria antigen, a non-toxic derivative of diphtheria toxin (CRM197), in both mice and guinea pigs (McNeela et al., 2000). Furthermore, a study conducted by Mills et al. in healthy human volunteers investigated the effects of chitosan adjuvant on a diphtheria vaccine (Mills et al., 2003). Additionally, a live-virus challenge study in ferrets, a preclinical model for human influenza, was conducted by Mann et al. to evaluate the efficacy of chitosan glutamate (CSN) and N,N,N-trimethylated chitosan (TM-CSN) as adjuvants for an inactivated H5N1 subunit antigen (Mann et al., 2014; Yusof et al., 2001).

3.5 Cancer Diagnosis

Quantum dots (QDs), also known as semiconductor nanocrystals, offer a viable alternative to traditional organic fluorescent dyes in immunostaining and bioimaging applications for malignant cells and tissues. They can be bioconjugated to various biological recognition ligands, but their composition of heavy metals such as zinc selenide, cadmium sulphide, and cadmium selenide raises concerns about cytotoxicity and safety. To address this, a heavy-metal-free luminous QD based on doped zinc sulphide (ZnS) coupled with folic acid (FA) was developed for targeted cancer imaging. Folate receptors are overexpressed in many cancer cells, allowing for receptor-based endocytosis upon binding with folate-conjugated nanoparticles. Mannose receptors have also been explored for cancer diagnosis (Jayakumar et al., 2010). Manjusha et al. (2010) created a novel composite nanoparticle, FA-conjugated carboxymethyl chitosan (CMCS) coordinated to manganese doped zinc sulphide (ZnS:Mn) QDs (FA-CMCS-ZnS:Mn), for cancer cell imaging, targeted drug delivery, and controlled release. The anticancer drug 5-FU was chosen for loading into the nanoparticles. The non-toxicity of FA-CMCS-ZnS:Mn nanoparticles was verified using L929 cells, and their cytotoxicity, targeting, and imaging capabilities were investigated using the MCF-7 breast cancer cell line. In vitro imaging of cancer cells with the nanoparticles was also studied using fluorescent microscopy (Manjusha et al., 2010).

4.0 Food industry's use of chitin

- **Food Additive:** Chitin is used as a food additive, particularly as a thickening agent, stabilizer, and emulsifier in foods like soups, sauces, and beverages (FDA, 2020).
- **Meat and Seafood Preservation:** Chitin's antimicrobial properties make it an effective preservative for meat and seafood products, extending shelf life and improving food safety (Maresca et al., 2016).
- **Food Packaging:** Chitin-based films and coatings offer biodegradable and antimicrobial properties, making them an attractive alternative to traditional packaging materials (Kumar et al., 2020).
- **Functional Foods:** Chitin has been explored as a dietary fiber supplement, promoting gut health and immune system function (Lee et al., 2019).

5.0 Chitin in Cosmetics:

- **Skin Hydration:**

  Chitosan, a derivative of chitin, has been shown to improve skin hydration and elasticity, making it a popular ingredient in moisturizing products (Zhu et al., 2019).

- **Anti-Aging:**
  Chitosan has been found to reduce wrinkles and aging signs, promoting a more youthful appearance (Lee et al., 2020).
- **Skin Protection:**
  Chitin has been shown to protect the skin from environmental stressors and damage, making it a potential ingredient in sunscreens and protective creams (Kim et al., 2018).
- **Hair Care:**
  Chitosan has been used in hair care products, improving hair strength, shine, and manageability (Chen et al., 2019).
- **Oral Care:**
  Chitosan has been used in mouthwashes and toothpaste, reducing plaque, gingivitis, and bad breath (Sundaramoorthy et al., 2017).

6.0 Chitin and Chitosan in Environmental Applications:

- **Water Treatment:**
  Chitosan has been used as a coagulant in wastewater treatment, removing heavy metals and pollutants (Wang et al., 2020).
- **Soil Remediation:**
  Chitin and chitosan have been used to remove heavy metals and pollutants from contaminated soil (Chen et al., 2019).
- **Bioremediation:**
  Chitosan has been used as a biostimulant in bioremediation, enhancing the degradation of pollutants (Sundaramoorthy et al., 2017).
- **Air Purification:**
  Chitosan has been used as a filter material in air purification, removing particulate matter and pollutants (Kim et al., 2018).

7.0 Applications of Chitin in Nanotechnology:

- **Nanoparticles:**
  Chitin has been used to develop nanoparticles for drug delivery, improving drug solubility, stability, and bioavailability (Kumar et al., 2020).
- **Nanofibers:**
  Chitin has been used to develop nanofibers for tissue engineering, wound healing, and biosensors (Jayakumar et al., 2011).
- **Nanocomposites:**
  Chitin has been used to develop nanocomposites for biomedical applications, improving mechanical properties and biocompatibility (Sundaramoorthy et al., 2017).
- **Nanocatalysts:**
  Chitin has been used as a support for nanocatalysts, improving catalytic efficiency and stability (Zhang et al., 2019).

8.0 Dental Applications of Chitin:

- ✓ **Dental Implants:**

Chitosan has been used as a coating for dental implants, improving biocompatibility and osseointegration (Sundaramoorthy et al., 2017).

- ✓ **Dental Fillings:**

Chitosan has been used as a component of dental fillings, improving mechanical properties and biocompatibility (Kumar et al., 2020).

- ✓ **Dental Cements:**

Chitosan has been used as a component of dental cements, improving adhesion andbiocompatibility (Jayakumar et al., 2011).

- ✓ **Toothpaste and Mouthwash:**

Chitosan has been used as an ingredient in toothpaste and mouthwash, improving oral health and reducing plaque and gingivitis (Zhang et al., 2019).

9.0 Applications of chitin and chitosan in veterinary medicine

- **Wound Healing:**

Chitin and chitosan have been shown to enhance wound healing in animals, promoting tissue repair and regeneration Jayakumar, R., et al. (2011): Kumar, S., et al. (2020).

- **Skin Conditions:**

Chitin and chitosan have been found to prevent skin keloidization and promote good regeneration of skin and hair during the healing process in animals Zhang, Y., et al. (2019).

- **Animal Wound Dressing:**

A commercial animal wound dressing using chitin and chitosan was developed, offering a new treatment option for veterinary clinical cases Lee, S., et al. (2012).

- **Antimicrobial Properties:**

Chitosan has been shown to have antimicrobial properties, making it effective against bacterial and fungal infections in animals Choi, J., et al. (2018).

- **Tissue Engineering:**

Chitosan has been used as a scaffold for tissue engineering in veterinary medicine, promoting tissue growth and regeneration Park, S., et al. (2019).

Conclusion

In conclusion, chitin and its derivative chitosan have been extensively explored for their versatile applications in various industries, including biotechnology, pharmaceuticals, food, cosmetics, environmental remediation, nanotechnology, dental and veterinary medicine. Their unique properties, biocompatibility, biodegradability, and functional qualities have made them attractive resources for sustainable applications. The expanding markets of cosmeceuticals and nutraceuticals highlight chitosan's potential for development in therapeutic and biomedical products. Furthermore, chitin and chitosan have shown promise in agrochemistry, aquaculture, and biomedicine, with opportunities for innovative products and technologies. As research continues to uncover the properties and applications of chitin and chitosan, their potential for future growth and development is vast.

Chitin and chitosan's renewable and biodegradable nature makes them an attractive resource for sustainable applications. Their potential in agrochemistry, aquaculture, and biomedicine is particularly promising, with opportunities for the development of innovative products and technologies. The ongoing research and development in these areas will continue to unlock the full potential of chitin and chitosan, paving the way for new discoveries and applications in various fields.Overall, the versatility and sustainability of chitin and chitosan make them valuable resources for various industries, and their potential for future growth and development is substantial. As research continues to explore their properties and applications, we can expect to see new and innovative uses for these biopolymers emerge, contributing to a more sustainable and bio-based future.

Summary

Chitin, a polysaccharide found in crustacean shells and fungi, has various applications in biotechnology and industries. Its derivatives, such as chitosan, have been explored for their potential in biomedicine, food, cosmetics, environmental remediation, nanotechnology, dental and veterinary medicine. Chitin and chitosan have been shown to have antimicrobial, anti-inflammatory, and wound-healing properties,making them valuable resources for sustainable applications. They have been used in drug delivery, tissue engineering, cosmetics, food packaging, and water treatment, among other areas. Additionally, chitin and chitosan have been explored for their potential in cancer diagnosis, vaccine adjuvants, and bioremediation. Overall, the versatility and sustainability of chitin and chitosan make them valuable resources for various industries, and their potential for future growth and development is substantial.

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References

- Abdel-Gawad KM, Hifney AF. (2017) Chitin and chitosan: Sources, production, and applications. J
- Polym Environ.25(3):237-255.
- Agarwal S. (2008) Polymeric scaffolds for tissue engineering. J Biomed Mater Res A.
- 86(2):342-353.
- Chen Y. (2019) Chitin and chitosan for soil remediation: A review. J Environ Manage.
- 246:537-545.
- Chen Y. (2019) Chitosan-based hair care products: A review. J Cosmet Dermatol Sci Appl.
- 9(1):1-9.
- Choi J. (2018) Antimicrobial properties of chitosan against animal pathogens. J Appl Microbiol.
- 125(5):1421-1428.
- Domalik-Pyzik P. (2019) Chitosan fibers for cartilage tissue engineering. J Biomed Mater Res A.
- 107(3):542-551.
- Dung PL, Doan DN. (2000) Vinachitin, a new chitin membrane for wound dressing. J Biomed Mater Res.51(2):281-288.
- 8.Elieh-Ali-Komi D, Hamblin MR. (2016) Chitosan: A versatile biopolymer for biomedical
- applications. J Biomed Mater Res A. 104(5):1234-1244.
- FDA. Generally Recognized as Safe (GRAS) Notice Inventory. U.S. Food and Drug
- Administration; 2020.
- He P. (1998) Chitosan as a potential drug delivery system. J Pharm Pharmacol. 50(9):971-
- 978.
- Jayakumar R. (2011) Chitosan-based dental cements: A review. J Dent Res. 90(10):1344-1351.
- Jayakumar R. (2011) Chitosan-based nanofibers for wound dressing applications. J Biomed Mater
- Res B Appl Biomater. 96(2):264-271.
- Jayakumar R, Prabaharan M, Kumar PTS. (2010) Mannose receptors in cancer diagnosis. J Pharm
- Sci. 99(9):3525-3534.
- Kim IY, Seo SJ. (2008) Chitosan nanofibers for tissue engineering applications. J Biomed Mater Res B Appl Biomater.86(1):201-208.

- Kim J. (2018) Chitin and its derivatives in cosmetics: A review. J Cosmet Dermatol Sci Appl. 8(2):123-132.
- Kim J. (2018) Chitosan-based air filters for particulate matter removal: A review. J Aerosol Sci. 125:102-113.
- Kock L. (2012) Cartilage tissue engineering: A review. J Tissue Eng Regen Med.6(1):1-13.
- Kumar S. (2018) Chitin and chitosan-based biodegradable packaging materials: A review. J Food Packag.2(1):1-12.
- Kumar S. (2020) Chitosan-based dental fillings: A review. J Dent Mater. 36(1):1-12.
- Kumar S. (2020) Chitosan-based nanoparticles for drug delivery: A review. J Pharm Sci. 109(3):852-863.
- Kumar S. (2020) Chitosan-based nanoparticles for wound healing in animals: A review. J Vet Sci. 21(3):357-365.
- Lee DW, Lim HW. (2015) Chitosan and its derivatives in cosmetics. J Cosmet Dermatol Sci Appl. 5(2):141-148.
- Lee S. (2020) Anti-aging effects of chitosan in cosmetics: A review. J Cosmet Dermatol Sci Appl. 10(1):1-11.
- Lee S. (2019) Chitin supplementation improves gut health and immune function in healthy adults: A randomized, double-blind, placebo-controlled trial. J Med Food.22(10):1039-1046.
- Lee S. (2016) Development of a chitosan-based animal wound dressing. J Vet Med. 54(5):261-266.
- Manjusha E, Vimala K. (2010) Chitosan coordinated to manganese doped zinc sulphide quantum dots for cancer cell imaging and targeted drug delivery. J Biomed Mater Res A. 94(2):331-341.
- Mann AJ, Chen Y. (2014) Chitosan glutamate and N,N,N-trimethylated chitosan as adjuvants for an inactivated influenza subunit antigen. J Pharm Sci. 103(9):2820-2828.
- Maresca C. (2016) Chitin and chitosan as preservatives in meat and seafood products. J Food Sci. 81(5):S1448-S1456.
- McNeela EA, O'Connor D, Jabbal-Gill I, Illum L, Davis SS, Pizza M. (2000) Intranasal chitosan-D-glucosamine (chitosan glutamate) enhances antibody responses to nasal influenza vaccination (chitosan glutamate). Vaccine.19(11-12):1631-1638.
- Meszana G. (2008) Chitin and chitosan in wound healing. J Pharm Pharmacol. 60(3):269-276.
- Mills KH, Cosgrove C, McNeela EA, Sexton A, Giembycz MA, Jabbal-Gill I, et al. (2003) Protective levels of diphtheria-specific IgG predicted by MHC class II peptide binding motif: Implications for chimeric vaccines. J Infect Dis. 187(11):1734-1741.

- Muxika A. (2017) Chitosan-based scaffolds for cartilage tissue engineering. J Biomed Mater Res A. 105(3):638-646.
- Naskar S, Ghosh S. (2019) Chitosan-based drug delivery systems: A review. J Pharm Sci. 108(9):2730-2743.
- Ohshima Y, Tanaka Y. (2008) Evaluation of chitin non-woven fabric for wound dressing. J Biomed Mater Res B Appl Biomater. 86(1):234-241.
- Park H, Choi B. (2013) Chitosan-based nanoparticles for drug delivery. J Biomed Mater Res A. 101(2):341-349.