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A REVIEW ON NATURAL POLYMER: CHITOSAN

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ABSTRACT

Chitosan is a natural, biodegradable polymer derived from chitin, which is mainly obtained from the shells of crustaceans such as shrimp, crab, and lobster. Due to its unique properties like biocompatibility, non-toxicity, biodegradability, and mucoadhesive nature, chitosan has gained significant attention in pharmaceutical and biomedical fields. This review focuses on the source, preparation, chemical structure, and various properties of chitosan, including physical, chemical, and biological characteristics. It also highlights the advantages and limitations associated with its use. Furthermore, the review discusses the wide range of applications of chitosan in drug delivery systems, wound healing, tissue engineering, food preservation, and water treatment. Special emphasis is given to its role in controlled and sustained drug delivery, where it works through mechanisms such as swelling, gel formation, diffusion, erosion, and permeation enhancement. Overall, chitosan is considered a promising natural polymer with extensive potential in modern drug delivery and biomedical applications, although certain limitations like pH-dependent solubility and variability need to be addressed

KEYWORDS: Chitosan, Natural polymer, Drug delivery system, Biodegradable, Biocompatible, Mucoadhesive, Controlled release, Nanoparticles, Biomedical applications.

INTRODUCTION

Chitosan is a natural, biodegradable polymer obtained from chitin, which is found in the shells of crustaceans like shrimp, crab, and lobster. It is widely used in pharmaceutical, biomedical, and food industries due to its excellent properties such as biocompatibility, non-toxicity, and bio adhesiveness.

It is considered one of the most promising natural polymers for drug delivery systems.

Source and Origin

- Derived from **chitin** (second most abundant natural polymer after cellulose)
- Sources:
  - Shrimp shells
  - Crab shells
  - Lobster shells
  - Fungal cell walls

Preparation of Chitosan

Chitosan is prepared by **deacetylation of chitin**.

Steps

1. **Deproteinization**
   - Remove proteins using NaOH
2. **Demineralization**
   - Remove minerals (like calcium carbonate) using HCl
3. **Deacetylation**
   - Treat chitin with strong NaOH → converts into chitosan

Chemical Structure

- Linear polysaccharide
- Composed of:
  - D-glucosamine
  - N-acetyl-D-glucosamine

Contains **amino ($-NH_2$) groups**, which make it:

- Positively charged
- Reactive and versatile

PROPERTIES OF CHITOSAN

Physical Properties

- White to off-white powder
- Odourless
- Insoluble in water
- Soluble in acidic solutions (like acetic acid)

Chemical Properties

- Cationic polymer (positive charge)
- Forms gels easily
- Can form films and beads

Biological Properties

- Biodegradable
- Biocompatible
- Non-toxic
- Antimicrobial activity
- Mucoadhesive

ADVANTAGES OF CHITOSAN

1. Biodegradability

Chitosan is naturally degraded by enzymes like lysozyme in the human body into non-toxic products.

This makes it safe for long-term use in drug delivery systems without harmful accumulation.

2. Biocompatibility

It is highly compatible with biological tissues and does not cause irritation or immune reactions.

Suitable for **oral, topical, and injectable formulations**.

3. Non-Toxic Nature

Chitosan is considered safe and non-toxic even at higher doses.

Widely used in pharmaceutical and biomedical applications without major safety concerns.

4. Mucoadhesive Property

Chitosan can adhere to mucosal surfaces (like nasal, buccal, intestinal lining).

This increases **drug residence time** and improves drug absorption and bioavailability.

5. Permeation Enhancer

It can open tight junctions between epithelial cells.

Enhances the transport of drugs across biological membranes, especially for poorly absorbed drugs.

6. Controlled and Sustained Drug Release

Chitosan forms gels and matrices that slow down drug release.

Helps maintain **constant drug levels in the body for a longer time**.

7. Antimicrobial Activity

It has inherent antibacterial and antifungal properties.

Useful in **wound healing, dressings, and infection control**.

8. Film and Gel Forming Ability

Chitosan can easily form films, hydrogels, beads, and nanoparticles.

Useful in

- Tablet coating
- Transdermal patches
- Microspheres

9. Versatility in Drug Delivery Systems

Can be used in

- Tablets
- Nanoparticles
- Microspheres
- Hydrogels

Suitable for multiple routes of administration.

10. Eco-Friendly and Natural Source

Derived from natural sources like crustacean shells.

Environmentally friendly and sustainable polymer.

DISADVANTAGES OF CHITOSAN

1. Poor Solubility at Neutral and Alkaline pH

Chitosan is only soluble in acidic conditions ($pH < 6$).

This limits its use in physiological conditions (pH ~7.4).

2. Variable Quality

Properties depend on:

- Source (shrimp, crab, fungal)
- Degree of deacetylation
- Molecular weight

This leads to **batch-to-batch variation**, affecting consistency.

3. Low Mechanical Strength

Chitosan films and matrices are relatively weak.

Often requires combination with other polymers for better strength.

4. Limited Stability

Chitosan can degrade over time, especially in presence of moisture and enzymes.

Reduces shelf life of formulations.

5. High Production Cost (After Processing)

Though raw material is natural, purification and processing steps are expensive.

Increases overall formulation cost.

6. pH-Dependent Drug Release
Drug release from chitosan systems depends on pH.

Unpredictable release in different parts of the body.

7. Possible Allergic Reactions
Since it is derived from shellfish, it may cause allergic reactions in some individuals.

Needs careful consideration in sensitive patients.

8. Limited Drug Compatibility
Not suitable for all drugs, especially those unstable in acidic conditions.

Restricts its universal application.

9. Rapid Swelling in Acidic Medium
Chitosan swells quickly in acidic conditions.

Can cause **initial burst drug release** instead of controlled release.

10. Difficult Large-Scale Standardization
Due to natural origin, maintaining uniform quality at industrial scale is challenging.

Affects reproducibility of formulations

APPLICATIONS OF CHITOSAN
Chitosan is a very versatile natural polymer, and what makes it special is how easily it can adapt to different uses. Because it is safe, biodegradable, and interacts well with the human body, it has found applications in many fields, especially in pharmaceuticals and healthcare.

1. Pharmaceutical Applications
In the pharmaceutical field, chitosan is widely used as a **drug carrier**. It helps in delivering drugs in a more controlled and effective way.

One of its most important uses is in **controlled and sustained drug delivery systems**. Chitosan can form a gel-like matrix around the drug, which slows down the release of the drug over time. This means the medicine works for a longer duration and does not need to be taken frequently.

Chitosan is also used in the preparation of **tablets, capsules, microspheres, and nanoparticles**. In nanoparticle form, it can carry drugs directly to the target site in the body, which improves the effectiveness of the drug and reduces side effects.

Another important application is in **mucoadhesive drug delivery systems** such as nasal, buccal, and ocular delivery. Chitosan sticks to mucosal surfaces, which helps the drug stay longer at the site of action and improves absorption.

2. Biomedical Applications
Chitosan plays a major role in the biomedical field due to its compatibility with human tissues.

It is commonly used in **wound dressings**. Chitosan not only protects the wound but also promotes faster healing. Its antimicrobial property helps prevent infection, and it also supports tissue regeneration.

In **tissue engineering**, chitosan is used to develop scaffolds that help in the growth of new tissues like skin, bone, and cartilage. These scaffolds act as a support system where cells can grow and repair damaged tissues.

Chitosan is also used in **drug delivery implants** and **gene delivery systems**, where it helps in safely transporting genetic material into cells for therapeutic purposes.

3. Food Industry Applications
In the food industry, chitosan is mainly used for its **antimicrobial and preservative properties**.

It is used as an **edible coating** on fruits and vegetables. This coating acts as a protective layer that slows down spoilage and increases shelf life.

Chitosan is also used as a **food preservative** because it can inhibit the growth of bacteria and fungi. This helps in keeping food fresh for a longer time without using harmful chemicals.

4. Cosmetic Applications
Chitosan is widely used in cosmetics because it is gentle on the skin and hair.

In **skin care products**, it acts as a moisturizer and forms a protective film on the skin, preventing dryness.

In **hair care products**, chitosan is used in shampoos and conditioners. It improves hair texture, adds shine, and provides a smooth feel.

It is also used in anti-aging products because it helps maintain skin hydration and elasticity.

5. Agriculture Applications
In agriculture, chitosan is used as a **plant growth enhancer** and **natural pesticide**.

It helps plants grow better by improving their resistance to diseases. It also acts as a **biopesticide**, protecting crops from harmful microorganisms without damaging the environment.

Chitosan is also used in **seed treatment**, where it improves germination and plant health.

6. Water Treatment Applications
Chitosan is used in water purification because of its ability to bind with impurities.

It acts as a **flocculating agent**, which means it helps in removing dirt, heavy metals, and harmful particles from water.

Because it is natural and non-toxic, it is considered an eco-friendly option for water treatment.

7. Textile Industry Applications
In the textile industry, chitosan is used to improve fabric quality.

It provides **antimicrobial finishing** to fabrics, which prevents the growth of bacteria and reduces odor.

It is also used to improve dye absorption and make fabrics more durable and skin-friendly

PROPERTIES OF CHITOSAN
Chitosan has gained a lot of importance as a natural polymer mainly because of its unique combination of physical, chemical, and biological properties. These properties make it highly useful in pharmaceutical and biomedical applications.

1. Physical Properties
Chitosan is usually found as a **white to off-white powder**. It is **odorless and tasteless**, which makes it suitable for use in oral formulations like tablets and capsules.

One important point is that chitosan is **insoluble in water**, but it becomes soluble in **acidic solutions** such as acetic acid. This behavior is very important because it affects how the drug is released in the body.

Chitosan also has good **film-forming ability**, which means it can easily form thin layers or coatings. Because of this, it is often used in tablet coating, transdermal patches, and wound dressings.

Another key property is its ability to **absorb water and swell**. When it comes in contact with fluids, it swells and forms a gel-like structure. This swelling plays a major role in controlling drug release.

2. Chemical Properties
Chemically, chitosan is a **linear polysaccharide** made up of repeating units of glucosamine and N-acetyl glucosamine.

The most important feature of chitosan is the presence of **amino (-NH_2) groups**. These groups give chitosan a **positive charge (cationic nature)**, especially in acidic conditions.

Because of this positive charge:
- It can interact with negatively charged substances (like cell membranes and proteins)
- It shows strong **mucoadhesive properties**
- It can form complexes with drugs and other polymers

Chitosan is also **chemically reactive**, which means it can be easily modified. Scientists often modify chitosan to improve its solubility, strength, and drug delivery performance.

3. Biological Properties
One of the biggest advantages of chitosan is its excellent biological behavior.

It is **biodegradable**, meaning it can be broken down naturally in the body by enzymes into harmless substances.

It is also **biocompatible**, so it does not cause irritation or toxicity when used in the body. This makes it safe for medical and pharmaceutical applications.

Chitosan has **antimicrobial properties**, which means it can inhibit the growth of bacteria and fungi. This is why it is commonly used in wound healing and food preservation.

Another important property is **mucoadhesion**. Chitosan can stick to biological surfaces like the lining of the nose, mouth, or intestine. This helps drugs stay longer at the site of action and improves absorption.

4. Mechanical Properties
Chitosan can form **films, gels, and fibers**, but its mechanical strength is **moderate** compared to synthetic polymers.

On its own, it may not be very strong or flexible, so it is often combined with other polymers to improve:
- Strength
- Elasticity
- Stability

This property is especially important when designing drug delivery systems and biomedical devices.

5. Thermal Properties
Chitosan is relatively stable at moderate temperatures, but it **decomposes at higher temperatures**.

It does not have a sharp melting point like synthetic polymers. Instead, it undergoes **thermal degradation** when heated strongly.

This property must be considered during processing and formulation.

6. Solubility Behavior

One of the most important properties of chitosan is its **pH-dependent solubility**.

- Soluble in acidic pH (< 6)
- Insoluble in neutral and alkaline pH

Because of this

- It dissolves in the stomach (acidic environment)
- It remains insoluble in the intestine

This property is very useful in designing **site-specific drug delivery systems**.

7. Swelling and Gel Formation

Chitosan has a strong ability to **absorb water and swell**.
When it swells:

- It forms a gel-like structure
- It controls the release of the drug

The extent of swelling depends on:

- pH
- Degree of deacetylation
- Molecular weight

This property is key for **sustained and controlled drug delivery**.

8. Degree of Deacetylation (DDA)

This is a very important characteristic of chitosan.
It represents how much chitin has been converted into chitosan.

- High DDA → more amino groups → better solubility and reactivity
- Low DDA → less reactive

It directly affects

- Solubility
- Charge
- Drug release behavior

9. Molecular Weight

Chitosan can have **low, medium, or high molecular weight**, and this affects its performance.

- Low molecular weight → better solubility, faster drug release
- High molecular weight → stronger structure, slower drug release

This helps in designing different types of drug delivery systems.

10. Mucoadhesive Property

Chitosan can strongly adhere to mucosal surfaces due to:

- Electrostatic interaction
- Hydrogen bonding

This results in:

- Increased drug residence time
- Improved bioavailability

MECHANISM OF CHITOSAN IN DRUG DELIVERY

Chitosan plays a very important role in drug delivery systems because of how it behaves inside the body. Its mechanism is not just one single process—it works through a combination of swelling, adhesion, diffusion, and interaction with biological membranes.

1. Swelling and Gel Formation

When chitosan comes in contact with biological fluids (especially in acidic environments like the stomach), it starts **absorbing water and swelling**.

As it swells:

- It forms a **gel-like structure** around the drug
- This gel acts as a **barrier** between the drug and the surrounding fluid

Because of this barrier, the drug does not release immediately. Instead, it is released slowly over time.

2. Diffusion-Controlled Drug Release

Once the gel layer is formed, the drug molecules start moving out slowly.

- Drug travels from **inside the matrix** → **outside medium**
- This movement is called **diffusion**

The thicker the gel layer

- Slower the drug release
- Better the sustained release effect

This is one of the main mechanisms responsible for **controlled drug delivery**.

3. Erosion of Polymer Matrix

Over time, chitosan begins to **break down (erode)** due to:

- Enzymatic action (like lysozyme)
- Continuous exposure to body fluids

As the polymer erodes

- More drug is released
- Drug release becomes a combination of **diffusion + erosion**

4. Mucoadhesion (Sticking to Body Surfaces)

Chitosan has a **positive charge**, while biological membranes (like intestinal lining) have a **negative charge**.

Because of this:

- Chitosan **sticks strongly to mucosal surfaces** (nose, mouth, intestine)

This leads to:

- Increased **residence time** of drug
- Better **drug absorption**
- Improved **bioavailability**

5. Opening of Tight Junctions (Permeation Enhancement)

One of the most unique features of chitosan is its ability to improve drug absorption.

It works by

- Temporarily **opening tight junctions** between epithelial cells

This allows

- Drugs (especially large or poorly absorbed drugs) to pass easily
- Enhanced transport across biological membranes

This is very useful for drugs that normally have **low permeability**.

6. Ionic Interaction with Drugs

Chitosan can interact with drugs through **electrostatic forces** because of its positive charge.

- Binds with negatively charged drugs or molecules
- Forms **complexes or carriers**

This helps in

- Stabilizing the drug
- Controlling its release

7. pH-Dependent Behavior

Chitosan behaves differently at different pH levels:

- In **acidic pH (stomach)** → soluble and swells
- In **neutral pH (intestine)** → becomes less soluble

Because of this

- Drug release can be **site-specific**
- Useful for targeting drugs to specific parts of the body

8. Nanoparticle-Based Delivery Mechanism

When used in **nanoparticle form**, chitosan shows advanced drug delivery behavior:

- Encapsulates the drug inside nanoparticles
- Protects drug from degradation
- Targets specific tissues

Mechanism

- Nanoparticles attach to cell membrane
- Enter cells via **endocytosis**
- Release drug inside the cell

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