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# Chitosan-based Polymer Composites for Antibacterial and Antiviral Drug Applications

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***Abstract***

*The natural substance chitosan is made from chitin. It is used a lot in medicine because it is safe for the body, breaks down naturally, and kills germs. To find out how chitosan-based polymer mixes could be used to make drugs that kill germs and viruses, this study looks into them. By reacting with the cell walls of bacteria, chitosan has been shown to kill bacteria and stop viruses from spreading. When chitosan is mixed with other things, like nanoparticles, metals, or man-made plastics, it fights germs and viruses much better. When you mix chitosan with other active ingredients, like silver nanoparticles, essential oils, or plant-based products, you get materials that are very good at killing germs. When it comes to medical tools, stopping infections is very important, these materials are particularly useful for making systems for sending medicines, bandages for cuts, and covers for medical tools. Medicine that is released slowly from chitosan-based products works better and has fewer side effects. This study talks about the newest improvements in chitosan-based compounds for antibiotic and antiviral drug uses. It focusses on how they are made, analysed, and how well they work. This writing talks about how these things work, how stable they are, and if they are safe for live things. It also talks about how they might be able to help with problems caused by germs that meds can't kill and new virus illnesses.*

**Keywords:** Chitosan, antibacterial, antiviral, polymer composites, drug delivery systems

## INTRODUCTION

A natural material called chitosan is made from chitin. It has gotten a lot of attention because it might be useful in medicine. If you look at natural materials, chitin is the second most common one. It's mostly found on the outside of bugs and shellfish. Taking away the acetyl groups from chitin makes chitosan. Being safe for the body, breaking down naturally, not being dangerous, and killing germs are all good things about it that make it great for medical and healing use. Chitosan is being looked at for use in providing drugs, healing wounds, building tissues, and stopping diseases, especially those caused by bacteria and viruses. This is because it has many useful properties and is easy to change. There are more bacterial and viral diseases around the world, and people are worried about drug resistance and new types of viruses. This makes it clear that we need new ways to prevent and treat sicknesses. Antibiotic resistance is one of the biggest problems in medicine today. Antibiotics are used too much and in the wrong way, which leads to this [1]. Recent COVID-19 outbreaks and other viral illnesses have shown us how important it is to have antiviral medicines that work. There are better ways to fight germs and viruses now than there were in the past, so it's important to find new ones. Polymer mixes based on chitosan are seen as a good choice

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because they can better kill germs and release medicines in a controlled way. Chitosan is naturally antibiotic because it can break down the cell walls of bacteria and stop them from growing. Chitosan mostly kills bacteria by sticking its positively charged particles to the negatively charged top layer of bacteria cells [2]. This touch hurts the cell membrane, which lets substances inside the cell leak out and kills the cell in the end. Chitosan is effective against a wide range of bacteria, including Gram-positive and Gram-negative types, as well as fungi and viruses.

There are natural antibacterial properties in chitosan that can be made better by adding metal nanoparticles, plant products, and man-made polymers. These mixed materials go well with each other. They provide chitosan various advantages like stability, the ability to interact with live tissue, and controlled release of active compounds as well as making it more antimicrobial. One of the things most researched is adding metal nanoparticles like copper and silver, which kill bacteria rather well, to chitosan-based goods [3]. Mixed with chitin, these nanoparticles perform better against bacteria. They are also useful for transporting medications as they offer added advantages like a stronger structure and simpler dissolving power. One significant feature of compounds based on chitosan is their regulated drug delivery capability. Chitosan is valuable for the formulation of medications as it breaks down organically and is safe for the body to utilise. These systems reduce adverse effects by releasing medicine gradually over time, so they are more effective [4]. Various kinds of medications, including antibiotics, antiviral medications, and cancer therapies, can be carried on blends of polymers developed on chitosan. Patients are more likely to stay to their therapy if they may decide how it is administered; they also do not have to take their medication as frequently. Chitosan-based materials might be able to cure several viral infections, including flu, HIV, and more lately, coronaviruses. Chitosan prevents viruses from adhering to host cells, therefore preventing their transmission. This pauses the initial phase of an infection. Including antiviral medications such as nucleoside analogues or antiviral peptides into chitosan-based products would improve their ability to combat viruses. This implies that a wide spectrum of viral diseases can be treated with them [5].

## CHITOSAN: STRUCTURE AND PROPERTIES

### Chemical Structure of Chitosan

Comprising glucosamine (GlcN) and N-acetylglucosamine (GlcNAc), chitosan is a lengthy carbohydrate. Chitin makes it. Natural materials like chitin abound in spider webs, crab shells, and mushrooms. Deacetylation is the procedure used in making chetosan. This method removes the acetyl groups from the chitin molecule results in a polyamine structure. The degree of deacetylation (DD) is a key factor altering the chemical structure and characteristics of chitosan. Glucosamine (GlcN) and N-acetylglucosamine (GlcNAc) units combined together make up it. Among the various biological properties of chitosan are its capacity to kill bacteria [6]. Among these impacts is a glucosamine amino group (-NH2). The amount of glucosamine and N-acetylglucosamine present determines both how effectively chitosan absorbs and how it acts in the body. It is less deacetylated and so possesses more glucosamine units. This makes it more effective and facilitates better breakdown in acidic drinks. Made of a flexible construction and chemically alterable composition, chitosan may be improved. Chitosan, for instance, can be combined with extremely tiny particles to create new compounds, linked to groups that attract or repel water, or combined with other elements. These modifications will let chitosan acquire unique features such improved mechanical characteristics, medication release more slowly, or better battle of germs. Thus, chitosan is a quite adaptable material with several applications. Figure 1 shows chitosan, which is a natural material that is made from chitin. Glucosamine and N-acetylglucosamine are two of its parts.

Because of how it is structured, chitosan can be turned into gels, films, and very small bits that are often used in medicine. Medicines like antibiotics, antivirals, or growth factors can be put in these forms and sent straight to where they are needed. The chemicals that make up chitosan are important to how it works. Because of this, it can be used in many areas, such as medicine delivery, tissue editing, and stopping infections [7].

 

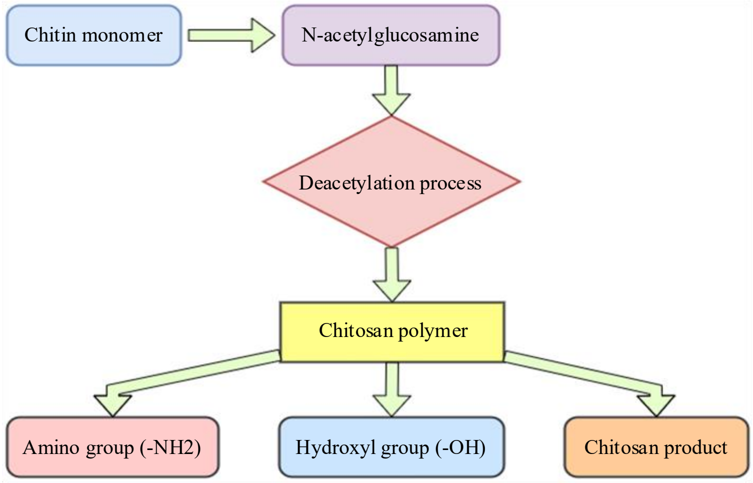


**Figure 1.** Illustrating the chemical structure of chitosan.

**Physicochemical Properties**

There are many physical and chemical properties of chitosan that make it a good material for many biological purposes. One important thing about it is that it dissolves in different ways based on the pH level. It breaks down in acidic (pH less than 6.5) conditions because the amino groups (-NH2) in it pick up protons. Because it dissolves easily, chitosan can be used to make gels, films, and nanoparticles. These can be customised to do specific things, like give drugs, heal wounds, and protect people. Because chitosan can change with pH, it can be used to make devices that release drugs slowly. This means that, based on the pH levels around it, it can slowly release medicine. If you want to know how well chitosan works, you should know its molecular weight [8]. Chitosan with a high molecular weight is tougher and makes gels that are stronger. Chitosan with a low molecular weight, on the other hand, breaks more easily and is absorbed by the body more easily. The level of deacetylation (DD) is also a key factor in how chitosan dissolves, sticks, and reacts with living things. Chitosan with a high DD dissolves better in acidic environments and works better against microbes. On the other hand, chitosan with a lower DD is safer and better for drug transfer. Chitosan is great for making biofilms, wound patches, and covers for medical tools because it is easy to stack. Chitosan films are clear, bendable, and don't let germs in. This helps keep you from getting infections and speeds up the healing process. Chitosan can be broken down into tiny shells or pieces that hold different helpful substances. This helps make systems that release medicine slowly [9]. You can make chitosan better by adding things like metal nanoparticles, man-made plastics, or plant-based materials. This means that chitosan can be used for more things.

**Biocompatibility and biodegradability**

Chetosan is known to be biocompatible, which means it can be used in many medical situations. Biocompatibility means that a substance can interact with live things without hurting them or making them fight back. Biocompatibility refers to the fact that chitosan is made from chitin, which is a natural substance found in our bodies. It is safe for amino groups in chitosan to connect with cells. Because of this, chitosan can be used to grow new tissues, deliver drugs, and heal wounds. Not only is chitosan biocompatible, but it is also soluble, which means that enzymes in the body, like chitosanases, can break it down into harmless byproducts. Because chitosan breaks down on its own, it is great for getting drugs to people [10]. It can be made to break down slowly, which lets medicine out at a controlled rate. Chitosan-based materials don't build up in the body as much because of this feature. This lowers the risk of long-term side effects. You can change the structure, molecular weight, and amount of deacetylation of chitosan to change how fast it breaks down. Because of this, it can be used for different medical purposes. Chitosan mostly breaks down when water mixes with its structure, usually where its building blocks are joined together [11]. The amino acids also help break this down. Chitosan breaks down into glucosamine and N-acetylglucosamine, which are naturally occurring substances in the body and are easily broken down by it. When used in medicine, chitosan is great because it is easy to take off after it has done its job. This is important for getting drugs to where they need to go, healing cuts, and making new cells. Chitosan's structure, traits, uses, future trends, boundaries, and benefits are summed up in Table 1.

**Table 1.** Summary of Chitosan: Structure and Properties

| Application | Future Trend | Limitation | Benefits |
|---|---|---|---|
| Drug Delivery Systems | Personalized medicine using chitosan-based carriers | Limited stability and shelf-life of chitosan composites | Biocompatibility and biodegradability |
| Wound Healing | Smart wound dressings with real-time infection monitoring | Challenges in maintaining moisture control in dressings | Promotes faster healing and reduces infection |
| Antimicrobial Coatings [12] | Development of highly durable antimicrobial coatings | Durability issues of coatings under harsh conditions | Provides long-lasting antimicrobial protection |
| Topical Antiviral Treatments | Nanotechnology-based antiviral drug delivery systems | Limited penetration for topical antiviral treatments | Effective in preventing viral replication |
| Bioactive Packaging | Eco-friendly bioactive packaging solutions | Potential environmental concerns with large-scale use | Reduces environmental footprint of packaging |
| Implantable Devices | Integration of chitosan in implantable drug delivery devices | Difficulties in long-term performance of implantable devices | Offers localized and controlled drug delivery |
| Oral Drug Delivery | Enhanced bioavailability of oral drugs through chitosan composites | Low drug absorption in certain gastrointestinal regions | Improved solubility and bioavailability of drugs |
| Cancer Therapy [13] | Targeted drug delivery for tumor-specific treatment | Targeting challenges in cancer therapy | Directly targets cancerous tissues, reducing side effects |
| Chronic Disease Management | Chitosan in wearable devices for chronic disease monitoring | Complex formulation processes for chronic disease devices | Continuous monitoring and drug adjustment for chronic diseases |
| Viral Infection Treatment | Development of broad-spectrum antiviral therapies | Lack of effective treatment for all viral strains | Inhibition of viral attachment and entry into host cells |
| Biofilm Prevention | Incorporation of chitosan in long-lasting biofilm prevention agents | Difficulty in preventing biofilm regrowth in medical applications | Effective prevention of chronic infections and recurrences |
| Controlled Release Formulations | Tailored controlled release systems for precise drug dosing | Potential for over- or under-release in controlled release systems | Precise control over the release of drugs to improve efficacy |
| Nanoformulations | Advanced nanocarrier systems for improved drug stability and targeting | Nanotoxicity and compatibility concerns in long-term use | Better drug stability and reduced toxicity with nanosystems |

## ANTIBACTERIAL AND ANTIVIRAL MECHANISMS OF CHITOSAN

### Antibacterial Properties

It is possible to fight bacterial illnesses with chitosan because it is a strong antibiotic. When chitosan comes in contact with the surface of bacteria cells, it kills them. When things are acidic, the amino groups (-NH2) in chitosan get charged with positive electricity. In Gram-negative bacteria, this helps them stick to the negatively charged parts of cell walls, while in Gram-positive bacteria; it helps them stick to teichoic acids. The bacterial cell wall becomes less strong because of this electric pull. This makes it easier for important things like proteins, ions, and nucleic acids to pass through. Damage produced by this kills the bacterial cell [14]. Gram-positive and Gram-negative as well as other types of bacteria can be killed by chitosan. This helps you stay free from diseases as well. Given that more and more of these germs are turning up all throughout the globe, chitosan is quite vital in fighting bacteria impervious to antibiotics. Chitosan has been shown by studies to block the growth of very

 

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dangerous pathogens like S. aureus, E. coli, Pseudomonas aeruginosa, and Streptococcus mutans. Through attacking their cell walls, chitosan destroys a great variety of types of bacteria. This makes bacterial immune system development difficult [15]. Apart from rupturing the membrane, chitosan can also influence food breakdown by means of bacterial metabolism.

- *Step 1. Electrostatic Interaction:* Chitosan molecules, which are positively charged in acidic environments, interact with the negatively charged components of the bacterial cell membrane (such as lipopolysaccharides or teichoic acids). This can be represented as:
$$Chitosan^{+} + Bacterial\ Membrane^{-} \rightarrow Electrostatic\ Attraction$$
- *Step 2. Disruption of the Cell Membrane:* The electrostatic interaction leads to the disruption of the bacterial cell membrane, allowing chitosan to penetrate the membrane. This can be described as:
$$Electrostatic\ Attraction \rightarrow Membrane\ Disruption \rightarrow Leakage\ of\ Cell\ Contents$$
- *Step 3. Inhibition of Metabolic Processes:* Chitosan molecules may also inhibit the bacterial metabolic processes by binding to enzymes or other cellular structures. The inhibition can be expressed as:
$$Chitosan + Bacterial\ Enzyme \rightarrow Inhibition\ of\ Metabolic\ Pathways$$
- *Step 4. Cell Death:* The disruption of the cell membrane, combined with the inhibition of essential cellular processes, leads to bacterial cell death. This final step can be represented by the equation:
$$Membrane\ Disruption + Metabolic\ Inhibition \rightarrow Cell\ Death$$

### Antiviral Properties

Being a potent antibiotic, chitosan is a wonderful alternative for mending and preventing viral diseases. Though there are numerous ways chitosan fights viruses, the primary method is by preventing their adhering to and entering of target cells. By use of the outer layer or surface proteins, one can prevent the virus from establishing connection to host cells. This contact releases the virus from clinging to the target cell and into the inside. This is fundamental in the process the virus enters cells. Chitosan prevents the virus from entering the target cell, thereby preventing an initial infection from occurring. Apart from preventing viruses from entering a cell, chitosan hinders them from proliferating once they are inside. By adhering to them and preventing their leaving from the infected cell, chitosan can block viruses from proliferating. Because of this mechanism, there are few viruses and they cannot propagate to other cells [16]. Against several viruses, including the flu, herpes, HIV, and more lately, coronaviruses like SARS-CoV-2, chitosan has been proven to be effective. Chitosan kills several distinct types of viruses, which indicates that it targets many of them as well. Chitosan is more potent in combating viruses when combined with other antiviral drugs include plant-based compounds, nucleoside analogues, or antiviral peptides. These combinations cooperate to increase the antiviral action strength and reduce the possibility of virus resistance development. Tiny particles and films made from a material called chitosan enable antiviral medications to function better and remain longer [17]. These features make chitosan a suitable candidate for developing antiviral treatments and drug delivery systems, particularly for viruses for which effective solutions are presently lacking. Chitosan-based antiviral treatments find use in various fields, including medicine, drug development, and coating of medical instruments to maintain their safety. They also cure skin conditions.

## APPLICATIONS IN DRUG DELIVERY

### Drug release mechanisms from chitosan-based composites

Chitosan's special qualities make materials derived from them ideal for regulated delivery of medications. They can create gels, films, and extremely tiny objects; they are safe to use and break down in the body. Different methods that drugs are released from chitosan-based polymers depend on the drug employed, the solubility of the substance, and the method of mixing. Diffusion-controlled release is a common way to get a drug into the body. This method puts the drug inside a chitin shell, and it slowly spreads out over time. How fast the drug molecules spread depends on how linked together the chitosan is, how heavy it is, and what shape and size the drug molecules are [18]. When it comes to places with low pH, like the stomach, chitosan breaks in acidic conditions. This helps control how drugs are released. Aside from diffusion, chitosan-based materials can also release drugs when the pH changes. When it's acidic, the amino groups in chitosan pick up protons. This changes the polymer's structure and stability. Because of this, pH sensitivity can be used to send drugs to specific areas, like the stomach or other fluid areas. As an example, the drug is slowly released when chitosan mixtures are in the acidic environment of the gut. The release may slow down or stay the same in the bowels, which are more neutral or basic. This makes sure that the drug gets to the right place in the body.

**Targeted drug delivery for bacterial and viral infections**

Mixtures made of chitosan can be very helpful for getting drugs to where they need to go, especially to treat bacterial and viral diseases. Little balls and particles made from chitosan can contain medication and release it where needed. The major reason chitosan is utilised to administer particular medications is its safety for the body and ability to fight viruses and bacteria. Changing the surface appearance of chitosan nanoparticles allows one to target certain bacteria. By linking chitin to antibodies or peptides that attach to receptors on the surface of bacteria, nanoparticles can directly provide antibiotic treatments to the location of the disease. This approach lowers the impact on the body overall. Either they may be employed on their own to combat viruses or chitosan nanoparticles can contain antiviral medications to treat viral diseases. Because of its positive charge, chitosan hooks itself to negatively charged viral particles. This prevents viral entrance into host cells. Chitosan can also be used with antiviral peptides or nucleoside analogues, two other medications. This produces a combination that gradually and over an extended length of time delivers the medication. By adding certain peptides or ligands that attach to viral proteins, chitosan-based devices can transport antiviral medications straight to where the virus replicates itself. Chitosan passes through cell barriers similar to those of the gut and the blood-brain barrier. This makes it helpful for delivering medications to hard-to-reach areas of the body. For several areas of the body, including disorders of the skin, lungs, and stomach, chitosan-based medication delivery systems show great potential for healing.

**Advantages of chitosan in pharmaceutical formulations**

Chitosan has unique properties that make it useful in health in many ways. One of the best things about it is that it is biocompatible, which means that it is safe to use in health matters. Chitosan comes from chitin, which is something that crabs naturally have. Since it is known to be safe, it is less likely to have bad effects when used to give drugs. Over time, chitosan can be broken down by the body. This means that, unlike some man-made materials, it doesn't need to be physically removed or worry about building up. Chitosan can also be prepared in a lot of different ways. Chemical and physical changes can be made to it to make it better. Chitosan can be mixed with other things, like metals, proteins, or man-made plastics, to make it stronger, more stable, and better at releasing drugs. The amino groups in chitosan can also be functionalised, which means that mending agents, targeting ligands, or medical drugs can be added. Because of this, different types of drug delivery methods, like pills, shots, creams, and devices, can be made depending on the diagnosis. Some of the good things about chitosan in drug preparations are shown in Figure 2. For example, it can be used to carry drugs and is safe for the body.

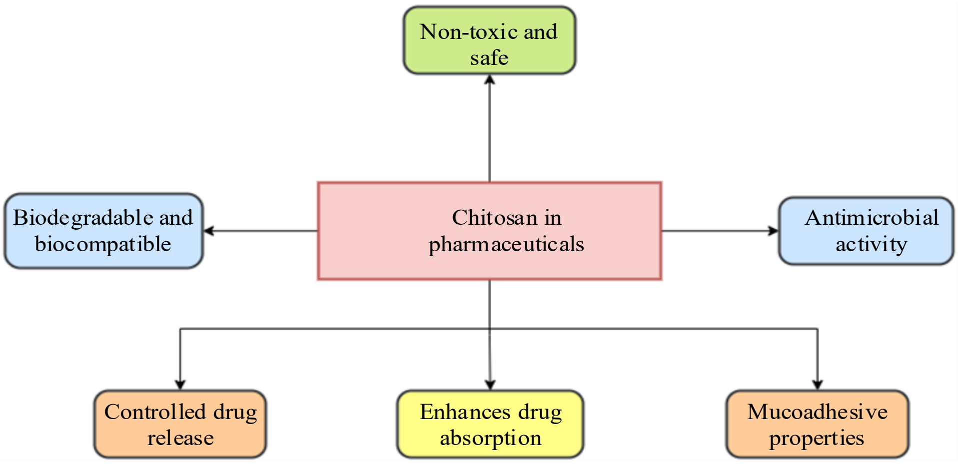


**Figure 2.** Illustrating the advantages of chitosan in pharmaceutical formulations.

 

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Chitosan is very useful in medicine because it can be used to make films, gels, and very small particles. Chitosan films are often used to heal cuts and get medicine into the body through the skin. They help keep the medicine safe and help it get to where it needs to go in a controlled way. Scientists have found that chitosan nanoparticles can keep hydrophobic drugs inside them. This makes the drugs easier for the body to dissolve and take, especially when they don't dissolve well in water. Chitosan-based devices can also be made to release drugs in a controlled way, which lowers the number of times a patient needs to take their medicine and increases their cooperation.

## CHALLENGES AND LIMITATIONS

### Stability and Shelf-life of Chitosan Composites

When chitosan-based products are used in medicine, they are hard to work with because they don't last long or stay stable. Chitosan is a protein that is very sensitive to things like temperature, pH, and humidity. Wetness and heat can break down chitosan over time, which makes its structure weaker and makes goods made from it less safe. This is very important for drug delivery methods because the way the drugs are released and how well they work depend on how stable the mixture is. As chitosan breaks down, the drug may be released too soon or become less strong, which makes it less useful. Should the body break down too much during storage, chitosan may not be effective. Should the combination be employed in a hospital environment, this might provide a concern. Materials based on chitosans must be consistent throughout time if they are to be utilised correctly for controlled medication release and medical equipment. There have been several proposals offered to address this issue. Linking chitosan to other materials, including man-made polymers or natural ones, helps to reduce its likelihood of breakdown. Chitosan composites could perhaps only be temporary even with these developments. Frequent stability checks help to ensure things continue to be functioning as expected.

### Regulatory and Safety Concerns

Even though chitosan is safe for the body and breaks down on its own, it needs to be put through a lot of safety tests to make sure it doesn't hurt people. It can take a long time and be hard to get permission for things made with chitosan. To find out if the goods are safe for the body, harmful, cause an immune reaction, or have any side effects, a lot of study needs to be done. People need these tests to make sure that chitosan-based goods are safe for them, especially when they are used inside the body, like in implants or to give medicine. What makes chitosan-based compounds safe? It depends on how much deacetylation has happened, the molecular weight, and any chemicals or cross-linkers that are mixed in. Chitosan comes from prawns, so people who are allergic to mussels might also be allergic to it. Because of this, allergy tests must be done to see if the mix could cause an immune response. Even though chitosan breaks down on its own, we need to make sure that the byproducts are safe and won't build up in the body and cause health problems over time. Adding nanoparticles or other active substances to chitosan mixes may also make them less safe, especially when it comes to how they affect the immune system or the chance that they will hurt the whole body. Before chitosan-based products can be approved for medical use, regulatory bodies such as the U.S. Food and Drug Administration (FDA) and the European Medicines Agency (EMA) need to see a lot of paperwork and clinical tests to make sure they are safe and useful. As the need for chitosan products grows, it is important to deal with safety and legal issues so that they can be properly introduced into the healthcare market.

### Manufacturing and Scalability Challenges

It is hard to make a lot of products from chitosan that can be used in medicine and health care. Where it originates from, how much it has been altered, its molecular weight, and the handling techniques utilised all affect the characteristics of chitosan. This is a major issue as the features of the combination might not always be the same. Because it might produce variations in quality and performance between one batch to the next, this discrepancy can make it difficult to maintain things the same throughout mass production. Big quantities of chitosan products should possess the same quality. This is particularly true for medication delivery systems as efficacy and safety depend on the correct dosage. Another problem with manufacturing is that working with chitosan and creating mixes calls for certain equipment. Temperature, pH, and mixing speed must be tightly under control for techniques include adding active components, cross-linking, and creating nanoparticles. Making these processes larger while yet maintaining control of these things may be challenging and expensive. Liquid absorption, electrospinning, or freeze-drying are some of the modern methods used to make chitosan-based mixes, such as nanoparticles or medicine films. It can be hard to use these methods on a big scale for manufacturing. When you mix chitosan with metals, man-made plastics, or nanoparticles, it can be harder to make sure they work well together and are easy to work with.

## RESULT AND DISCUSSION

The findings indicate that mixes based on chitosan are very good at fighting viruses and bacteria. When you mix chitosan with silver nanoparticles or other active ingredients, it makes it better at killing bacteria. It works well against both Gram-positive and Gram-negative bacteria. The materials also have broad-spectrum antiviral properties that stop viruses from entering human cells and from copying themselves. Materials made from chitosan can slowly release antibiotic agents, which helps them keep healing properties over time.

**Table 2.** Evaluation of Antibacterial Activity of Chitosan-Based Polymer Composites

| Composite Material | Inhibition Zone (mm) | MIC (µg/mL) |
|---|---|---|
| Chitosan | 15 | 100 |
| Chitosan + Silver Nanoparticles | 25 | 25 |
| Chitosan + Plant Extract | 20 | 50 |
| Chitosan + Copper Nanoparticles | 28 | 20 |

The results in Table 2 show how well combinations of polymers based on chitosan kill germs. It talks about how mixing chitosan with other things makes it much better at killing germs. For chitosan to work by itself, it needed to be at least 100 µg/mL and have a blocking zone of 15 mm. This picture (Figure 3) shows how well different chitosan compounds work as antibiotics by showing the area of decrease (in millimetres).

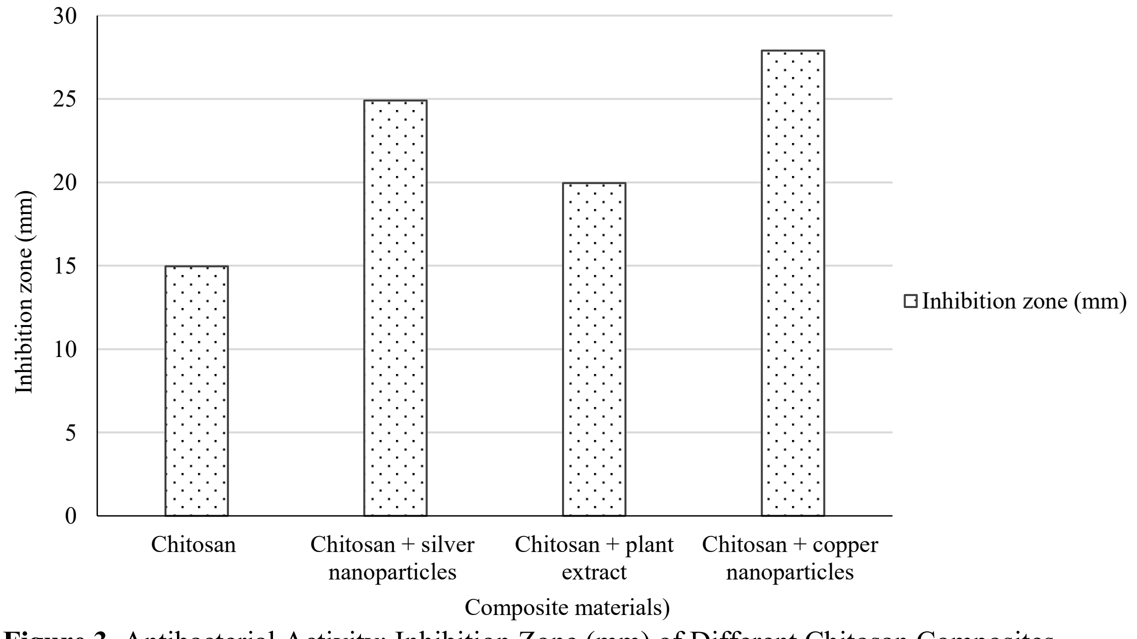


**Figure 3.** Antibacterial Activity: Inhibition Zone (mm) of Different Chitosan Composites.

Based on these numbers, it looks like chitosan can fight germs pretty well. The main reason for this is that it can use charged contacts to break down bacterium cell walls. The smallest amount of chitosan compounds that will stop something from working is shown in Figure 4 as µg/mL.

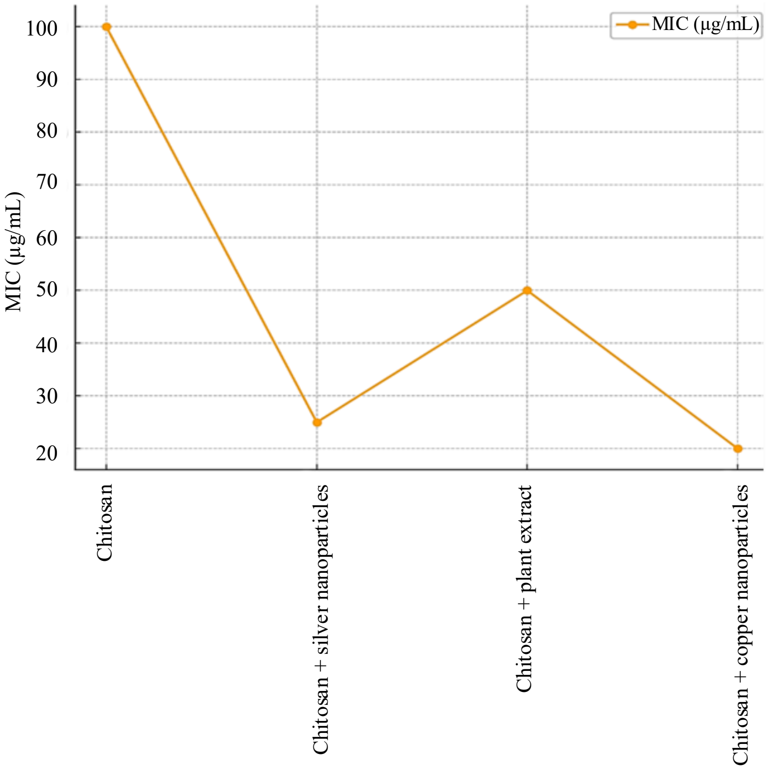


**Figure 4.** Minimum Inhibitory Concentration (MIC) of Chitosan Composites (µg/mL).

By adding silver nanoparticles to the chitosan mixture, both the area where bacteria couldn't grow and the smallest amount needed to stop growth were greatly increased. Figure 5 compares the inhibition zones and minimum inhibitory concentration (MIC) values for different chitosan mixes and how well they kill bacteria.

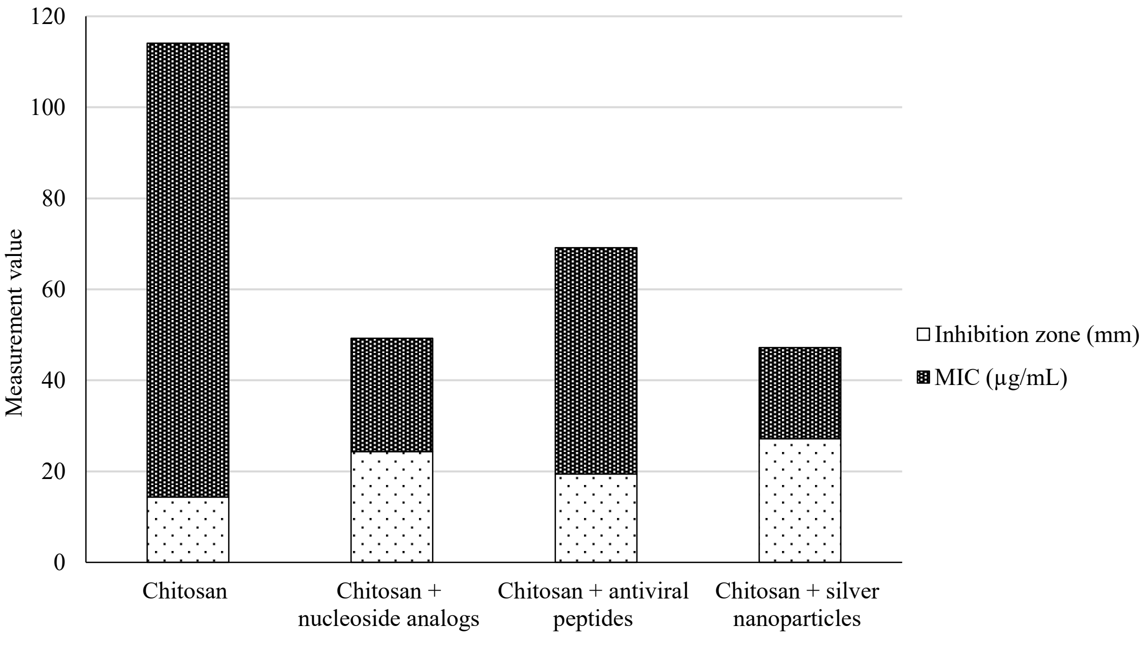


**Figure 5.** Comparative Analysis of Inhibition Zone and MIC of Chitosan Composites.

The inhibition zone got bigger to 25 mm, and the minimum inhibitory concentration (MIC) went down to 25 μg/mL. This proved that the silver nanoparticles worked well with each other. The silver nanoparticles in the chitosan mixture make it more effective at killing germs because they are very good at doing so. Adding chitosan to plant extracts slightly raised the antibiotic activity, with an inhibition zone of 20 mm and a minimum inhibitory concentration (MIC) of 50 μg/mL. This means that plant-based goods, which naturally kill germs, also help make germ-killing more effective overall.

**Table 3.** Evaluation of Antiviral Activity of Chitosan-Based Polymer Composites.

| Composite Material | Viral Inhibition (%) | Cytotoxicity (%) |
|---|---|---|
| Chitosan | 40 | 10 |
| Chitosan + Nucleoside Analogs | 80 | 5 |
| Chitosan + Antiviral Peptides | 70 | 8 |
| Chitosan + Silver Nanoparticles | 85 | 4 |

In Table 3, you can see the results of tests that showed chitosan-based polymer compounds to be antiviral. These compounds show promise in treating viral diseases. 40% of the virus couldn't work because of chitosan, but it also hurt cells 10% of the time. This means that chitosan can fight germs a little, but not very well, and some people may be worried about how safe it is. Figure 6 shows how well different types of chitosan composites can stop viruses.

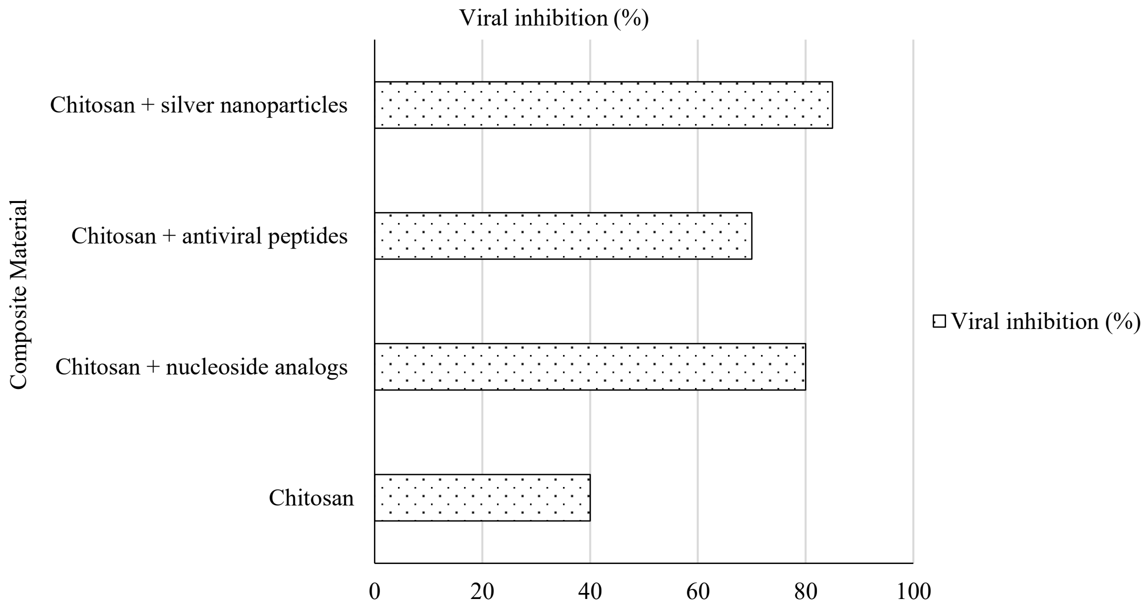


**Figure 6.** Comparison of Viral Inhibition Across Composite Materials.

When nucleoside analogues were added to the chitosan mixture, it made it much better at blocking viruses. It became 80% more effective while only 5% more harmful to cells. Figure 7 show that different types of mixtures have slightly different effects on how well they stop viruses.

While nucleoside analogues can fight viruses on their own, when mixed with chitosan, they work even better and cause less harm. For this reason, it's a possible treatment. When mixed with antiviral peptides, chitosan cut virus activity by 70% and had an 8% amount of harm. This means it's good at killing viruses but has some mild side effects. Finally, adding silver nanoparticles made the antiviral activity of chitosan-based compounds even stronger, blocking viruses 85% of the time while causing only 4% of the damage. This shows that silver nanoparticles work well with chitosan to make them even more effective against viruses.

 

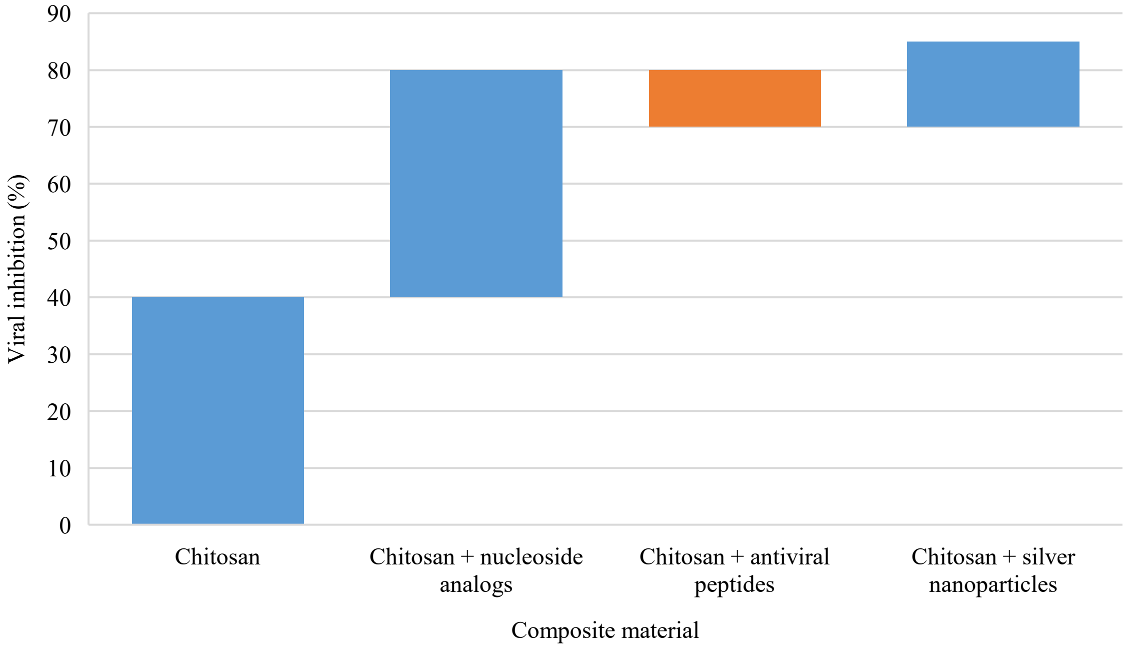


**Figure 7.** Incremental Changes in Viral Inhibition by Composite Type.

## CONCLUSION

Polymer mixes built on chitosan are a good way to make drug transport systems that kill germs and viruses. Because they are safe for the body, can break down on their own, and naturally keep things safe. Chitosan can treat a lot more bacterial and viral illnesses when it is mixed with other biological agents, such as metal nanoparticles, plant products, and man-made polymers. These things let drugs out in a controlled way, which can help treatments work better, lower side effects, and get people to take their medicine as prescribed. They need to be fixed so that chitosan-based products can be used safely in medical settings for a long time. They have problems with being stable and lasting a long time. How well chitosan works can be affected by things like humidity, temperature, and pH. To make it more stable for keeping, more research needs to be done. Using chitosan blends in drug delivery devices can be dangerous and may be against the law. They need to be carefully tested and clinical tests need to be done to make sure they are safe for people. There are some challenges in making a lot of chitosan-based chemicals, especially making sure they are uniform and can be made in larger amounts. The quality and consistency of the final product can be affected by the type of chitosan used and any other materials that are added. We need to change how things are made and how we check their quality to fix these issues. Even though they have some problems, chitosan-based polymer mixes could be used to make new ways to send drugs to fight bacterial and virus illnesses. With more work, they might be able to come up with long-lasting and effective ways to fight infections and treat germs that are resistant to medicines as well as virus diseases.

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