

# Controlled Release of Anti-Inflammatory Drugs from Biopolymer Matrices

N. S. Kulkarni<sup>1\*</sup>, Sawale J. A.<sup>2</sup>, Ram Garg<sup>3</sup>, Sneha Pawade<sup>4</sup>

## Abstract

Carefully releasing anti-inflammatory drugs from natural materials is a new way to make treatments work better and cut down on the side effects of current drug delivery methods. To slowly release drugs, this method uses safe, reusable materials. It's a good alternative to pills or shots. Anti-inflammatory drugs that are used to treat long-term conditions like gout and inflammatory bowel disease work better when they are made in a controlled release form. With these formulations, the medicine can be delivered steadily and precisely. Researchers are always looking into biopolymers like alginate, chitosan, collagen, and hyaluronic acid to see how well they can hold drugs and slowly release them. This helps the body hold on to the right amount of medicine for longer. You can make these polymers change how fast drugs are released based on things like the molecular weight, linking density, and pH or temperature outside the polymer. These biopolymer materials can be changed so that medicine goes straight to the areas that need it, which is very helpful for getting rid of pain in those areas. This study looks at recent progress made in making biopolymer devices that release drugs that reduce inflammation. Drugs can be released in a number of ways, such as through diffusion, dissolution, and growth. The book talks about how the properties of biopolymers change how drugs are released, which in turn changes how well treatment works.

**Keywords:** Controlled release, biopolymer matrices, anti-inflammatory drugs, drug delivery systems, biodegradable polymers

## INTRODUCTION

Biopolymer materials that allow controlled release of anti-inflammatory drugs are a big step forward in how medicines are given. Our bodies respond to harmful things by inflaming them. Rheumatoid arthritis, inflammatory bowel disease, and rashes are some of the long-term inflammatory diseases that

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affect millions of people around the world. NSAIDs, corticosteroids, and other anti-inflammatory drugs are often used to treat these diseases. These medicines can help ease symptoms, but if you take them for a long time, they might have bad side effects. One big problem with the old ways of giving drugs is that they don't work well for long periods of time to keep the body's medicine levels steady. This changes the amount of drug, which can make it less or more efficient depending on the person. These methods can also cause bad side effects because the drugs might not only reach the right places but also impact other systems. The goal of controlled release goods is to fix these issues by slowly releasing drugs over a longer period of time. This helps make the benefits last longer and have fewer side effects. It is possible for controlled release drug delivery devices to release medicine at

a set rate. This can happen in a number of ways, such as by spreading the drug out or breaking it down. The drug needs to get into the system or to where it needs to go in the body. For people with long-term health problems, these methods are very helpful. Patients are more likely to stick with their treatment, and drug levels in the blood stay fixed because they don't need to be taken as often. This lowers the chance of side effects and makes the medicine work better overall. It is best to use biopolymers for drug transfer because they are biodegradable, biocompatible, and flexible.

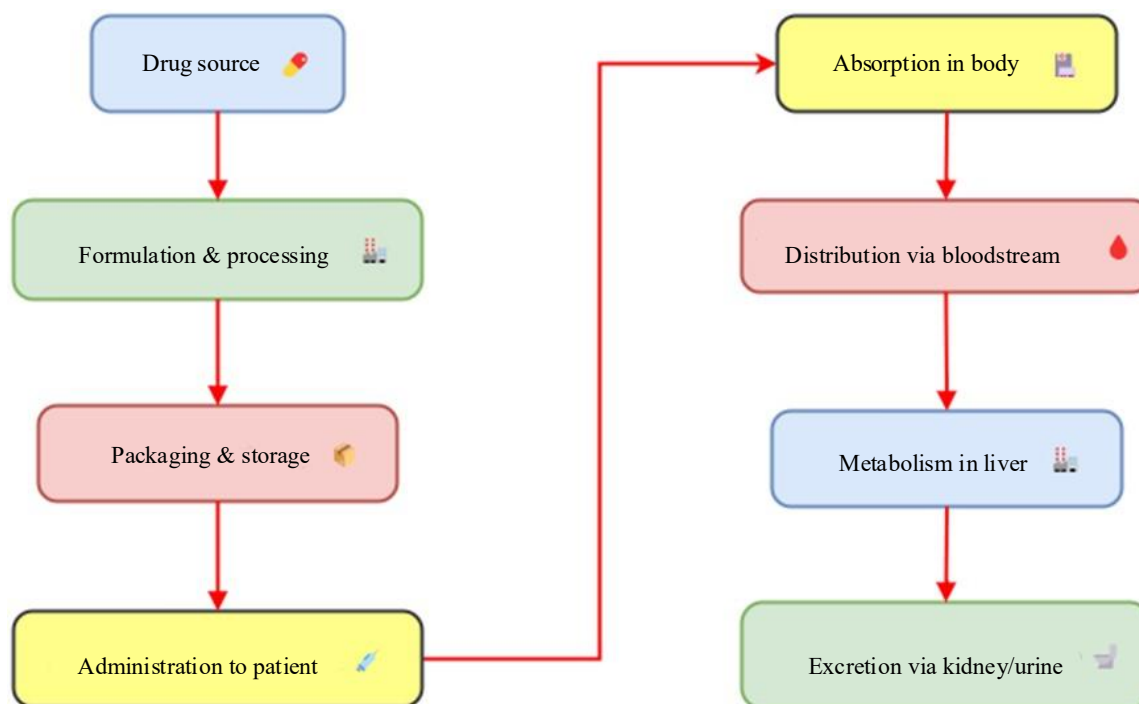
Biopolymers, which include proteins, polysaccharides, and other biopolymers that come from natural sources or are made in a lab, are good for limited drug release because of certain properties they possess. Structures made of these materials can hold drugs and slowly release them over time. People will need to take the medicine less often, but they will still get the care they need. Alginate, chitosan, collagen, hyaluronic acid, and gelatin are some of the biopolymers that are most often used in controlled release devices [1]. It's easy to change the chemical and physical properties of these biopolymers, which helps control how drugs are released. Anti-inflammatory drugs can be put on the skin, shot, or taken by mouth. But these normal ways of giving drugs make them less effective because the body quickly gets rid of them or they don't reach the swollen area evenly. Biopolymer materials can be used to make controlled release systems that are useful in many ways. They can send medicine to certain places and let it work slowly over time. The rate at which the medicine works can be changed based on what the patient needs [2]. Local drug delivery can be changed for these ways. This is especially helpful for treating inflammatory diseases that affect certain parts of the body, like inflammatory bowel disease or osteoarthritis. Site-specific drug release also lowers the amount of drug that gets into the body's systems, which lowers the risk of bad side effects. By changing the polymer materials used, new biopolymer-controlled release methods aim to improve how anti-inflammatory drugs are released. Scientists have looked into a number of ways to make drug packaging in these systems safer, more effective, and faster to release. These include joining, mixing, and adding nanoparticles. Nanoparticles and nanofibers make biopolymer matrices better by making it easier to control drug release, making it easier for the body to use the drugs, and letting more of them be given in a controlled way. You can also have more control over how drugs are released by using ways that adapt to changes in pH, temperature, or enzyme activity [3]. In other words, anti-inflammatory drugs can be sent right to the area where they are needed.

## **BACKGROUND AND LITERATURE REVIEW**

### **Conventional Drug Delivery Systems**

In traditional drug transport methods, medicines are commonly put on the skin, taken by mouth, or given through an IV. Because they are simple and easy to use, these ways are the ones that doctors most often use. But they often have some problems, especially when used to treat long-term conditions like inflammation. For instance, taking medicine by mouth can change how well the medicine works because the amount of the drug in the blood can rise and fall. Patients have to take their medicine often to make sure they have the right amount in their bodies. This can make it hard for them to follow their treatment plan. Most of the time, injectable types work well to treat the whole body, but they can be painful and may need to be given by a healthcare worker. Topical drug application usually works well for certain places, but it's not always the best way to treat deeper tissues, like when there is widespread inflammation [4]. There is a big problem with standard drug delivery methods in that you can't change how fast the medicine is released. Most of the time, the drug quickly enters the body, causing its effects to spike quickly. Its levels in the blood then drop sharply. Giving too little or too much medicine can happen because of this. This makes the medicine less useful and increases the chance of side effects. This picture (Figure 1) shows how drugs are usually given and how they are taken in, spread, and broken down in the body.

Also, standard methods don't always get drugs to the areas that are inflamed directly. This means that more of the body is exposed, which can make side effects more likely in healthy area. It is clear that we need new ways to send drugs that can work over time and release medicine in a controlled way [5]. In current medicine, this is very important for addressing diseases with long-term inflammation.



**Figure 1.** Illustrating the conventional drug delivery system.

### Advancements in Controlled Release Mechanisms

New improvements in controlled drug release methods are meant to fix the issues with older drug delivery systems by releasing medicines more regularly, reliably, and for a longer time. Because of these changes, drug delivery methods have been created that can control how quickly the medicine is released and keep the right amounts in the body for longer. You can divide controlled release methods into two main groups: systems that control spread and systems that control decay. Systems that control diffusion depend on how the drug moves through a polymer [6]. How easy it is for the drug and the polymer to move around affects how fast the drug is released. On the other hand, degradation-controlled systems rely on the matrix material breaking down slowly, which lets the drug inside out over time. To get a better handle on how chemicals are released, hybrid devices have been made that combine diffusion and breakdown. Also, changes in how drugs are given that are triggered have made it possible to control how drugs are released in new ways. Because they are made to respond to outside signs like pH, temperature, or enzymes present at the target area, these systems are known as "smart" delivery systems. So, pH-sensitive polymers help the drug only be released in the acidic part of the gut or in the swollen tissues of people with inflammatory bowel disease [7]. When the devices are at body temperature, they can release drugs. This makes them good for specific therapy. Nanomaterials, such as nanofibers and nanoparticles, have made it easier for drugs to get into the body. They let you better control how quickly drugs are released, help drugs be taken better, and make drugs that break down easily more stable.

### Properties and Types of Biopolymers Used in Drug Delivery

Biopolymers are becoming popular for drug administration because they can break down safely in the body, are friendly to living tissue, and can release medication over a long time. These polymers, which come from natural sources or are made to imitate natural materials, have several benefits over manufactured ones. They are less harmful and work better with biological systems. Choosing the right biopolymer is important for creating drug delivery systems because the qualities of the polymer affect how the drug is released, its safety, and how well the drug works [8]. The most frequently used biopolymers in medicine transport methods include carbohydrates, proteins, and their products. Polysaccharides such as alginate, chitosan, hyaluronic acid, and dextran are commonly used because they attract water. This helps create structures that can hold and slowly release drugs. Alginate comes from brown kelp and is commonly used because it can create gels easily. This makes it great for systems

that release drugs in a controlled way. Chitosan, which comes from chitin in crab shells, is a useful substance because it can kill germs, break down naturally, and improve how well drugs are absorbed. Proteins like collagen and gelatin are used to send medicines directly to certain areas of the body. Collagen is an important protein found in joint tissues. Using it in drug delivery methods can help heal wounds and support tissue repair [9]. Table 1 summarizes background, future trends, challenges, and scope of the application reviewed. Gelatin, a dehydrated form of collagen, is frequently used in controlled release products due to its ability to form hydrogels and its biocompatibility.

## BIOPOLYMER MATRICES FOR CONTROLLED RELEASE

### Types of Biopolymers (e.g., Natural Vs Synthetic)

Natural biopolymers and man-made biopolymers are the two main types. These are put into groups based on where they come from and how they are made. These biopolymers are natural and come from things like bugs, plants, and animals. Biopolymers are made up of proteins and sugars, such as collagen and gelatin and alginate, chitosan, and hyaluronic acid. Natural biopolymers are often used to deliver drugs because they are biocompatible and biodegradable, which means they don't cause bad immunity reactions when given to living things. Because the groups in natural polymers are flexible, we can change their properties to make drugs work better [12]. Made biopolymers, on the other hand, are made in labs using chemical synthesis. You can change a lot about synthetic biopolymers like PLGA, PCL, and PEI to make them work the way you want them to, like how quickly they break down, how strong they are, and how they release drugs. With these polymers, you can better control their size, form, and chemical functions. This makes it easier to make accurate methods for transporting drugs. Most of the time, synthetic biopolymers are more stable and rigid than natural ones. However, they need more tests to make sure they are safe for the environment and can break down properly [13]. Most of the time, the type of drug being used, how it should be released, and how the biopolymers will be used determine which one to use.

**Table 1.** Summary of Background and Literature Review.

Application	Future trend	Challenges	Scope
Chronic Inflammatory Diseases	Personalized Drug Delivery	Ensuring Consistent Drug Release	Improved Efficacy in Chronic Diseases
Osteoarthritis	Smart Biopolymer Systems	Matrix Stability	Minimized Side Effects in Osteoarthritis Treatment
Rheumatoid Arthritis	Nanoparticle-Based Matrices	Drug Degradation	Better Management of RA Symptoms
Psoriasis [10]	Site-Specific Drug Delivery	Controlled Release at Targeted Sites	Enhanced Efficacy in Skin Conditions
Asthma	Stimuli-Responsive Matrices	Scalability of Production	Reduction in Asthma Exacerbations
Inflammatory Bowel Disease	Combination Therapies	Overcoming Immune Responses	Improved Long-Term Management of IBD
Soft Tissue Injuries	3D-Printed Drug Systems	Cost-Effectiveness	Faster Recovery from Soft Tissue Injuries
Cancer Therapy	Therapeutic Protein Encapsulation	Long-Term Biocompatibility	Targeted Chemotherapy Delivery
Post-Surgical Recovery	Long-Term Drug Release Systems	Avoiding Drug Resistance	Faster Healing in Post-Surgery
Localized Pain Relief [11]	Targeted Inflammation Treatment	Systemic Side Effects	Localized Pain Relief with Fewer Side Effects
Wound Healing	Integrating Drug Release with Monitoring	Manufacturing Complexity	Enhanced Healing of Chronic Wounds
Gastrointestinal Disorders	Microfluidics for Localized Therapy	Regulatory Approval for Novel Systems	More Effective GI Disorder Treatment
Neuroinflammation	Combination of Biopolymer and Nanomaterials	Ensuring Drug Loading Efficiency	Targeting Neuroinflammatory Disorders

### **Advantages of Biopolymer Matrices in Drug Delivery**

Biopolymer matrices are becoming more and more popular as a way to give drugs because they have many benefits, especially when it comes to controlled release. One big benefit is that they work well with the body and don't hurt or make people nervous when they're used on people. Biopolymers are made to look like biological materials or come from natural sources. This makes them better for living cells than man-made polymers. This makes it less likely that something bad will happen, like redness or an infection. One more important benefit is that biopolymer materials can break down on their own after releasing the drug. This means that they can be taken out without surgery and won't leave any waste in the body. This feature lets engineers make systems that can be set up to release drugs at certain times, giving them more control and a more steady release [14]. This method lets the drug be given slowly, which helps the body's drug levels stay stable and work well. Not as many doses are needed, and there are not as many side effects from high drug levels. Lots of different kinds of drugs can be held in biopolymer structures, from small molecules to bigger ones like proteins and nucleic acids. Biopolymers can be changed to fit the drug being given by changing things like how well they stick to or pull away from water. In this way, the drug stays inside and is released in a controlled way [15]. It is possible to make biopolymer materials that target specific cells or processes. This helps get medicine to the right place. This focused method centres on a certain area, which lowers the amount of drug that gets into the body, lowers side effects, and makes the drug work better.

### **Mechanisms of Drug Release from Biopolymer Matrices**

Drugs released from biopolymer materials happen through different methods, mainly affected by the characteristics of both the polymer and the drug. Drugs can be released from biopolymer materials mainly through three ways: diffusion, dissolution, and growth.

- *Diffusion-controlled release:* In this method, the drug is placed inside a biopolymer material, and it is released as the drug gradually spreads through the polymer. How quickly a drug spreads depends on how big the drug molecules are, how much space is in the polymer, and how the drug interacts with the polymer. Hydrophilic biopolymers like chitosan and alginate often work this way: the drug goes from a place where there is a lot of it inside the material to a place where there is less outside the material.
- *Erosion-controlled release:* Erosion-controlled release happens when the biopolymer matrix itself gradually breaks down or weakens over time, releasing the drug in a controlled way as the matrix erodes. This method works well for biodegradable polymers like PLGA [16]. As the polymer breaks down in water, it slowly releases the drug. Erosion can happen in two ways: surface erosion, where the top layer wears away first, and bulk erosion, where the whole material breaks down more evenly.
- *Swelling-controlled release:* Some biopolymer materials expand when they come into touch with body fluids, which causes them to release the drug inside. In this process, the polymer material takes in water, causing it to expand and form pathways for the drug to be released. Hydrogels can hold a lot of water and are often used to release substances in a controlled way. You can control how much swelling happens and how fast the drug is released by changing how tightly the polymer is linked together or by altering its water-attracting or water-repelling qualities [17].
- *Stimuli-responsive release:* Besides regular methods, biopolymer matrices can be made to react to certain triggers like pH, temperature, or particular enzymes. These smart drug delivery systems release medicine only when they detect changes in the environment, allowing for precise and timely delivery. For instance, pH-sensitive materials are used in pills to release medicine only in the acidic parts of the gut or in areas of inflammation.

## **ANTI-INFLAMMATORY DRUGS AND THEIR APPLICATION**

### **Types of Anti-Inflammatory Drugs (E.G., Nsaids, Corticosteroids)**

Anti-inflammatory drugs are a group of medicines that help reduce swelling and pain. Inflammation can be a cause of many long-term health problems. Most of the time, NSAIDs and corticosteroids are

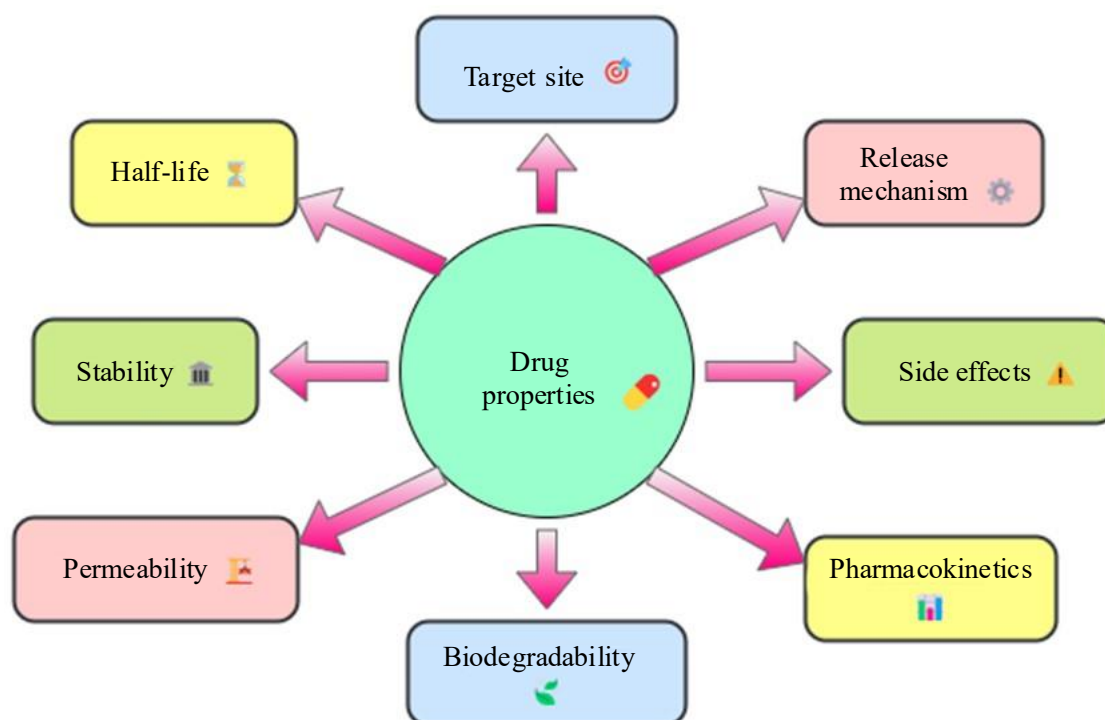
suggested as anti-inflammatory drugs. Over-the-counter pain killers (NSAIDs) like aspirin, ibuprofen, and naproxen are often used to treat rheumatoid arthritis, osteoarthritis, and soft tissue injuries. They stop cyclooxygenase (COX) enzymes from doing their job. Prostaglandins, which cause swelling, pain, and heat, are made by these enzymes. While NSAIDs can help ease pain and stiffness, they can also lead to heart problems, stomach ulcers, and kidney problems if they are used for a long time. Strong painkillers called corticosteroids, such as prednisone, hydrocortisone, and dexamethasone, can help reduce swelling. They do a lot of the same things that hormones made by the adrenal glands do [18]. These medicines work by stopping the immune system from doing its job and lowering the production of hormones that cause inflammation. When used to treat asthma, rheumatoid arthritis, and inflammatory gut disease, corticosteroids work very well at lowering inflammation. But using corticosteroids for a long time can cause bad side effects like osteoporosis, adrenal sadness, and being more likely to get infections. There are also biologics, like TNF inhibitors, and disease-modifying antirheumatic drugs (DMARDs), like methotrexate, that are used to treat inflammation. These are used for certain dangerous inflammation diseases. These medicines can help people with inflammatory diseases, but they are pricey and might have side effects, so they need to be carefully controlled.

### **Therapeutic Uses and Challenges in Delivery**

Anti-inflammatory drugs are very important for addressing a lot of health problems that cause inflammation. This includes long-term illnesses, crashes, issues with the immune system, and swelling in the lungs, stomach, and skin. There are certain amounts of these medicines that need to get to the swollen tissue in order for them to work well. One big problem with anti-inflammatory drugs is that they can make the body feel bad in many ways. Pain in the stomach, kidney problems, and heart problems can happen after taking NSAIDs for a long time. Corticosteroids are great at lowering swelling, but if you take them for a long time, you may lose bone strength, gain weight, and have a weaker immune system. To deal with these problems, engineers are making gadgets that can target specific areas of inflammation and release medicine in a controlled way. Creams and ointments are often used to treat joint pain or skin problems like eczema that cause redness. Still a big problem is getting drugs to reach deeper cells. When giving meds by mouth or IV, it's important to make sure they get to the right place slowly and without hurting the rest of the body. Careful changes need to be made to the drug's safety, how well it breaks, and how quickly it releases to get the best treatment results. Making sure that people do what they are supposed to do is another problem. People may not stick to their treatment plan as well if they have to take drugs that need to be taken often or have bad side effects. This makes the drugs less effective. The steady and focused delivery of drugs is made possible by controlled release formulas. This can help patients stick to their treatment by lowering side effects and the number of times they need to take medicine.

### **Drug-Specific Considerations in Controlled Release Systems**

It is important to think about the chemical makeup of the drug, the treatment goals, and the disease being targeted when making controlled release methods for anti-inflammatory drugs. It only takes a short time for NSAIDs to work, and they can have side effects all over the body. They are given slowly and regularly when controlled release methods are used. This means that patients don't have to take them as often and blood levels stay low. Matrix systems, such as hydrogels or microspheres, can hold NSAIDs and slowly release them over time, making sure that the right amount of medicine is always available. This is because corticosteroids are strong medicines that can have bad effects if they are not given properly, making them hard to work with in controlled release methods. Products with controlled release corticosteroids are made to deliver medicine straight to areas of inflammation, like the joints in people with rheumatoid arthritis. This method drops the amount of medicine that the body is exposed to generally, which lowers the risk of side effects. To give corticosteroids, researchers are looking into biodegradable drug delivery methods such as PLGA nanoparticles. These systems can spread out the medicine over a longer period of time, which lowers the risk of side effects happening all over the body. Figure 2 displays important details about each drug in controlled release systems, focussing on the rate of release and safety.



**Figure 2.** Drug-specific considerations in controlled release systems.

Another important factor for limited release methods is how stable the drug is. Some anti-inflammatory drugs can break down in the body, which can make them less effective and shorten how long they work. So, the delivery method chosen should keep the drug safe from things like pH changes and enzymes that can break it down, making sure the drug stays whole until it gets to where it needs to go. How quickly a drug is released is important when creating controlled release methods. The aim for both NSAIDs and corticosteroids is to keep the drug levels at a safe range. This means they should be high enough to reduce inflammation but not so high that they become harmful. The release rate can be affected by the drug's ability to dissolve, the characteristics of the polymer, and the surrounding environment. This means careful adjustments are needed when creating the recipe.

## FUTURE DIRECTIONS AND PROSPECTS

### Innovations in Biopolymer Matrix Design

Because of new discoveries in materials science, biotech, and nanotechnology, it is now much easier to make biopolymer materials that can carry drugs. More recent progress in biopolymer design aims to make the system that moves drugs more stable and effective, as well as better at storing and releasing drugs. Biopolymers that are smart and can respond to changes in their environment, such as pH levels, temperature, or certain enzymes, are a promising new idea. When the environment changes, these unique materials let drugs out. This lets medicine get to exactly where it's needed. Biopolymers that are sensitive to pH can release their contents in acidic places like the stomach or swollen tissues. This makes them great for healing inflammation in certain areas. Nanotechnology is being used to make biopolymer matrix, which is another area of growth. Putting nanoparticles, nanofibers, or nanogels into biopolymer materials can help them hold drugs better, control how quickly drugs are released, and keep the drugs safe. The nano-enabled materials can also help drugs work better, stop them from breaking down, and help healers get to the right areas more precisely. Also, making mixed biopolymers which are made of both natural and man-made polymers allows for more control over the matrix's mechanical, chemical, and breakdown properties. With this new idea, it's possible to make systems that can release medicine in a controlled way, making them fit different drugs and medical needs. Because of progress in 3D printing and bio fabrication, it is now possible to make devices that deliver drugs to specific people.

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### Emerging Trends in Controlled Drug Release

Material science, nanotechnology, and data-based drug-making methods that are getting better are affecting new trends in limited drug release. A big trend is making ways to send drugs that not only do so slowly but also have other health benefits. One example is that controlled release systems can be made to slowly release anti-inflammatory drugs along with imaging agents, biosensors, or mending proteins. This lets treatments be used together. These systems keep track of how the drug is working all the time and can change how the drug is given based on the needs of the patient. More and more drugs are being delivered to specific areas. New ways of distributing drugs are being developed so that they can go straight to where they are needed in the body, like a disease or inflammation spot. This helps keep side effects to a minimum in other areas of the body. Because the treatment goes straight to the area that needs it, this method is especially good for diseases like cancer. This makes it work better and keeps good cells from getting hurt too much. As nanotechnology improves, we can make systems that can directly target diseased areas by recognising specific marks or sensors. For example, we can make cases out of nanoparticles. In this way, drugs can be administered more correctly and more successfully. Some new gadgets made with 3D printing are being used to send medicine. With this technology, custom drug delivery methods can be made for patients that release medicine in a controlled way. The form and material of the drug capsule can be changed with 3D printing to make complicated patterns that change how drugs are released over time. 3D printing can also be used to make patches or implants that hold drugs. These can send medicine directly and steadily to certain areas, which can help with ongoing pain or recovery from surgery. Putting digital health tools and ways to move drugs together is a new and interesting area. With monitors or digital devices, smart drug delivery systems can give real-time information about how fast medicine is being given and how patients are responding. This mix makes it possible for more customised and adaptable treatment plans, which can make it easier to give medicines based on the needs of each patient.

### Potential Impact on Clinical Applications

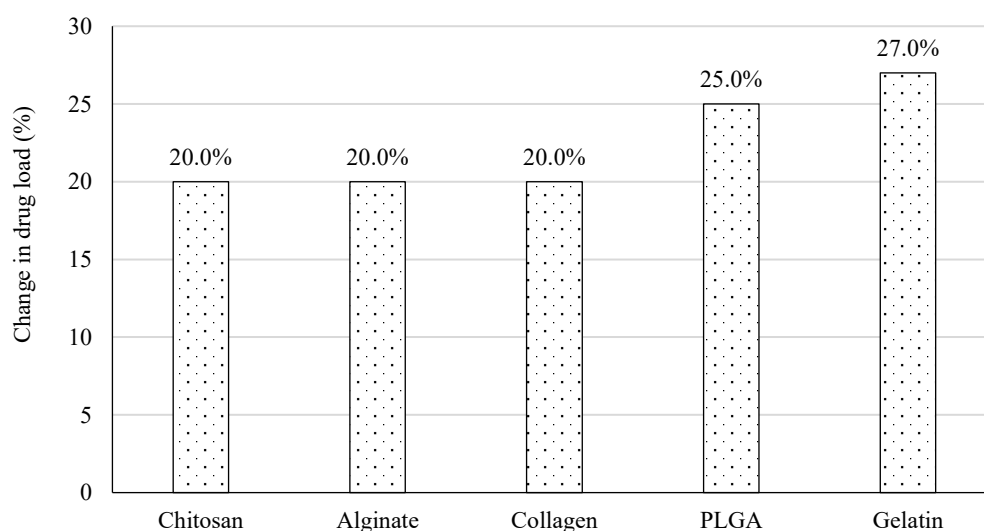
New discoveries in biopolymer design and controlled drug release systems are likely to have a big impact on medical treatments, especially for long-term illnesses, targeted inflammations, and other conditions that need long-term medicine. With controlled release ways, drugs are released slowly, so people don't need to take them as often. This helps people follow their treatment plan, which makes the medicine work better. People who have rheumatoid arthritis or other long-term inflammatory diseases can get better quality of life with controlled release medicines that help them deal with their symptoms over time with fewer side effects. One of the most important outcomes will be more tailored care. We can now make personalised drug systems that meet the needs of each patient thanks to new ways to move drugs. Medicine delivery devices that are 3D printed can be made to fit the body and health needs of a patient, for example. In the end, this means better and more focused care. Doctors will be able to change a patient's amount of medicine based on how well they respond to treatment, how bad their sickness is, and how their body breaks down the drug. Focused drug delivery systems, especially those that use nanoparticles or other nanomaterials, could also change the way diseases like cancer are treated, since targeted therapy is key to getting the most good effects while causing the least harm overall. The drug can get to the cancer more effectively with these ways, and there is also less chance of side effects that come up with regular treatment. Biopolymer drug delivery devices can help treat inflammatory diseases because they let doctors precisely control how and when drugs are released, going straight to the tissues that are hurt. This is especially helpful for people with inflammatory bowel disease, gout, or psoriasis, where treating certain areas is key to better controlling the condition.

### RESULT AND DISCUSSION

Biopolymer materials were able to release anti-inflammatory drugs in a controlled way. They were made up of protein-based polymers like collagen and carbohydrates like chitosan and alginate. How drugs like NSAIDs and corticosteroids are released relies on what they are made of, how tightly their structure is linked, and things like pH and temperature that are nearby. It was a mix of spread and disintegration that let the drugs out. It took longer for the drug to leave matrices with more polymer and better links. The findings show that biopolymer structures can slowly release painkillers in a certain area. This helps lower side effects and improve treatment outcomes.

**Table 2.** Drug Release Kinetics of Anti-Inflammatory Drugs from Biopolymer Matrices.

Biopolymer type	Initial drug load (%)	Cumulative release at 24 hrs (%)	Release rate (mg/day)	Half-life (hrs)
Chitosan	35	55	2.5	12
Alginate	40	60	3	16
Collagen	30	50	2	14
PLGA	45	70	3.5	20
Gelatin	38	65	3.2	18



**Figure 3.** Drug load change across biopolymers.

Table 2 shows how anti-inflammatory drugs are released from different biopolymer materials. It includes information about the initial amount of drug, how much is released after 24 hours, the release rate, and the half-life for five types of biopolymers: Chitosan, Alginate, Collagen, PLGA, and Gelatin. Chitosan can carry about 35% of a drug at first, and after 24 hours, it releases 55% of that drug. Figure 3 shows how the amount of drug changes among different biopolymers used in transport methods.

It releases 2.5 mg per day and has a half-life of 12 hours, which means it has a balanced release. This makes it a good option for short-term managed release. Alginate, starting with a drug amount of 40%, can release 60% of the drug over time and at a rate of 3 mg per day. This shows it can give the drug for a bit longer, with a half-life of 16 hours. Collagen is compatible with the body and has a low initial drug load of 30%. After 24 hours, it releases only 50% of the drug and has a slow release rate of 2 mg per day. Figure 4 shows how biopolymers release drugs, highlighting their release patterns and speed.

This makes it suitable for systems that need localised and slow drug release. PLGA has the highest starting drug amount of 45%. It releases the drug slowly, with a total release of 70% after 24 hours. The release rate is 3.5 mg per day, and it takes 20 hours for half of the drug to be released. Gelatin is in between collagen and PLGA, providing a good mix. It has an initial drug load of 38%, releases a total of 65% of the drug, and has a half-life of 18 hours, making it suitable for medium-term release.

The Table 3 compares different biopolymer materials for their ability to release drugs. It looks at factors like how well the drugs are captured, how stable they are, how long they release the drugs, and how easy they are for patients to use. The materials compared are Chitosan, Alginate, Collagen, and PLGA. Chitosan has a high encapsulation efficiency of 90% and maintains drug safety at 98% for 30 days, showing that it is very good at holding drugs. Figure 5 shows how well different biopolymer types can hold drugs and how stable the drugs are.

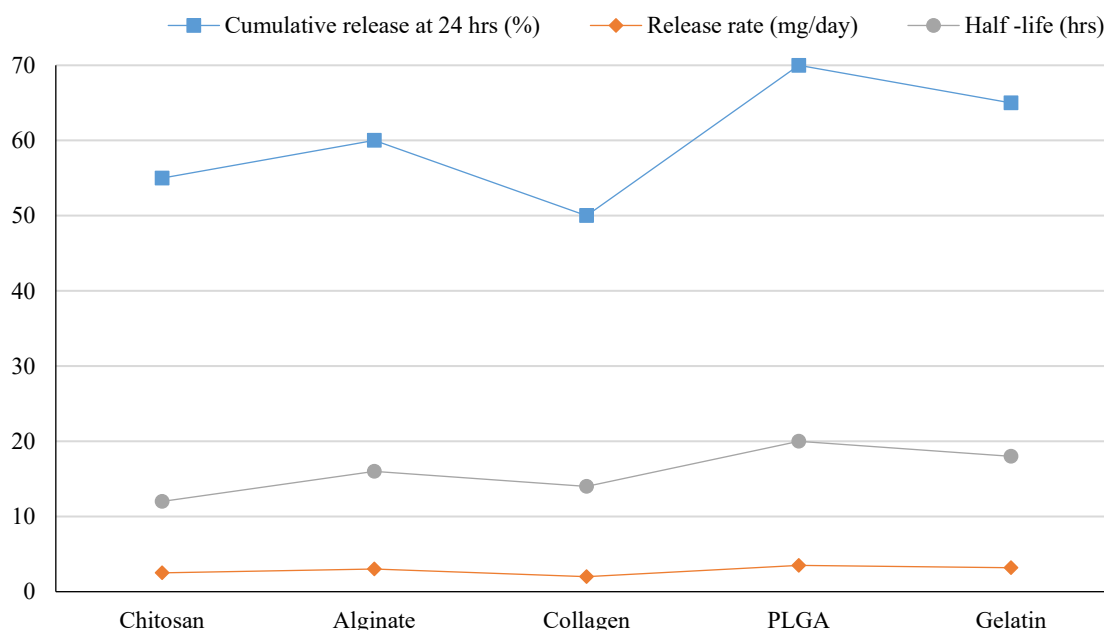


Figure 4. Drug release characteristics of biopolymers.

Table 3. Comparison of Biopolymer Matrices for Controlled Release Efficacy.

Biopolymer type	Encapsulation efficiency (%)	Drug stability (%) at 30 days	Release duration (days)	Patient compliance score (%)
Chitosan	90	98	7	82
Alginate	85	95	9	70
Collagen	88	97	8	75
PLGA	92	94	14	91

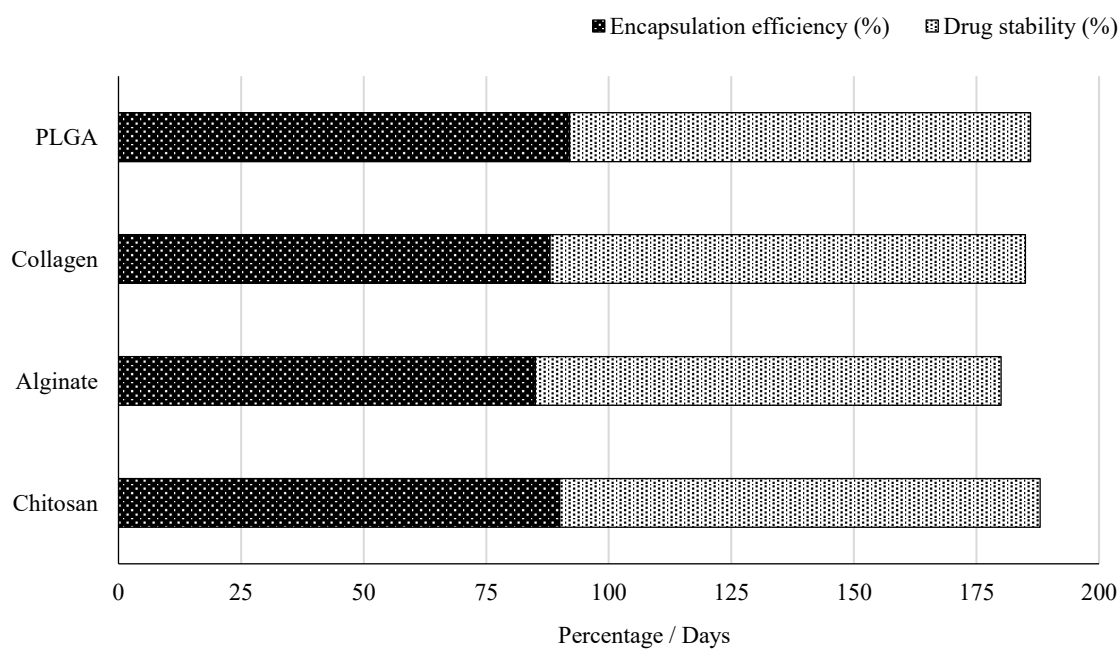
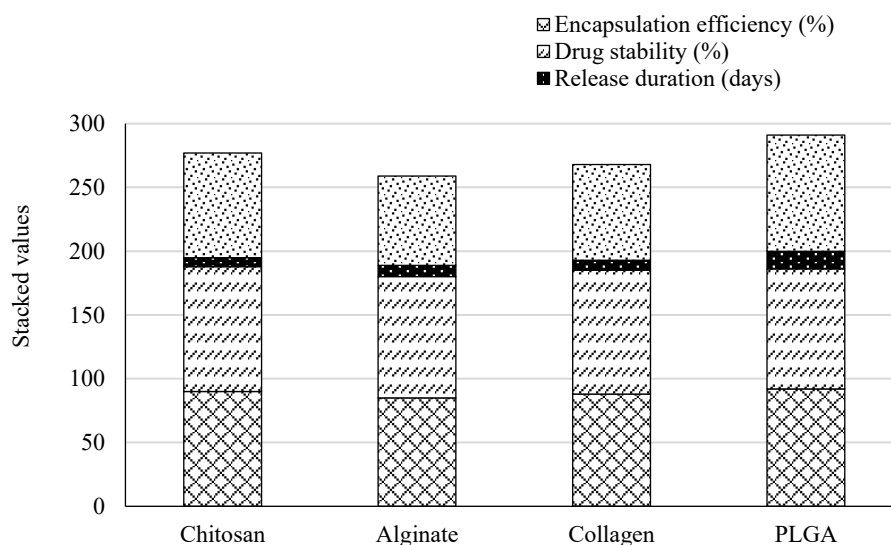


Figure 5. Encapsulation efficiency and drug stability across biopolymers.



**Figure 6.** Biopolymer characteristics: efficiency, stability, release, and compliance.

Its release time is faster (7 days), and the patient compliance number is 82%, which shows that patients accept it fairly well. This means that Chitosan works well to hold drugs but is likely better for short-term use. Figure 6 shows the features of biopolymers, focussing on how efficient they are, how stable they are, how they release substances, and how well they meet requirements.

Alginate encapsulates less effectively (85%) and has slightly lower drug safety (95%) than Chitosan, but it can release the drug over a longer period, up to 9 days. A patient compliance number of 70% indicates that patients may not be very satisfied, likely because of side effects or how often they need to take their medicine. Collagen can successfully hold 88% of the substances it contains and keeps the drug stable for 97% of the time. It gradually releases the drug over 8 days and has a compliance score of 75%. These results indicate that it is a good option for medium-term limited release uses.

## CONCLUSION

A possible way to make treatments for long-lasting inflammation more successful and better is to slowly release anti-inflammatory drugs from biopolymer materials. Using natural materials like alginate, chitosan, and collagen, we can make ways to deliver drugs that work directly and steadily. This cuts down on the number of doses needed and the bad affects. The managed release method depends on things like the surroundings, the type of material used, and how tightly it is bound. This lets the speed at which the medicine is given be changed to meet the needs of the treatment. Biopolymer design is changing, especially with the use of nanotechnology and bendable materials. These changes are making drug delivery methods more accurate and flexible. With these new ways, medicine can be sent straight to the area that is inflamed. This lowers the risk of side effects by keeping the rest of the body from coming into touch with it. Personalised drug transfer systems can be made for each patient using advanced production techniques such as 3D printing, which can improve the results of their treatment. Still, there are some problems to solve, such as making sure that the patterns of drug release are solid and constant, especially when the number of drugs made for clinical use goes up. Before these tools can be widely used, we also need to do clinical studies to see how safe they are and how well they work with the human body.

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