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Biopolymer-Based Nanocomposites for Oral Drug Delivery

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Abstract

Because they are biocompatible, biodegradable, and can hold a lot of different healing agents, biopolymer-based nanocomposites are looking like a good way to give drugs orally. These materials are made up of natural polymers mixed with nanoparticles. They have many benefits for drug delivery systems, such as making drugs more soluble, controlling when they are released, and making enclosed drugs more stable. Drug release rates may be altered by mixing nanoparticles metal or carbon-based particles into biopolymer frameworks. This enables focused and long-distance movement to certain digestive system sites. This strategy may solve the issues with current medication delivery systems including their undesirable side effects, fast breakdown rate, and poor performance of normal drugs. Selecting the appropriate biopolymers such as polysaccharides, proteins, or lipids which may then be transformed into nanocomposites utilising various techniques, like electrospinning, liquid casting, and coacervation helps one create biopolymer-based nanocomposites. The kinds of nanoparticles utilised, along with their size, form, and any surface modifications, determine how well the system distributes medications. Furthermore, the biopolymer structure protects the medicine within from being broken down by enzymes and outside stressors, therefore reaching its intended location intact. For the treatment of disorders requiring focused therapy in the digestive system, these nanocomposites might also be able to release medications in a regulated and particular manner. As the science advances, biopolymer-based nanocomposites together with existing production techniques offer great promise for improving oral medication delivery systems.

Keywords: Biopolymer-based nanocomposites, oral drug delivery, controlled release, biocompatibility, nanoparticles

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INTRODUCTION

The most often used and simple approach to provide medications to individuals is oral therapy. But it also often comes with issues like poor absorption, medications rapidly disintegrating in the GI system, and inability to regulate drug release speed. These issues are driving researchers explore more advanced methods to administer medications that would enable patients to have less side effects and better treatment. One alternative is biopolymer-based nanocomposites. Being biocompatible, biodegradable, and able to contain a variety of therapeutic compounds, they provide a possible platform for oral drug administration. Made from naturally occurring polymers derived from endlessly renewable resources, biopolymers are reusable. They consist of polysaccharides like starch and chitosan proteins like albumin and gelatin and lipids like

phospholipids). More and more, these materials are being used in medicine delivery systems because they are safe for humans and the environment and can work with biological systems. Adding them to nanocomposites along with nanoparticles like metal nanoparticles, carbon-based nanoparticles (like graphene oxide), and liposomes makes them better at carrying drugs and opens the door to controlled and targeted drug delivery. Better drug absorption, stability, and bioavailability—qualities very relevant for overcoming the challenges of conventional oral drug delivery—are among the features of the biopolymer-based nanocomposites developed. Because they can regulate medication release over a long period of time, biopolymer-based nanocomposites are excellent for oral drug administration. Common methods of oral medicine intake, tablets and pills, can release the medication all at once. Side effects and variations in medication levels in the body might follow from this. Nanocomposites are better than standard ways of giving drugs by mouth in a number of ways, such as making drugs more soluble, controlling how much they are released, and making them more stable. Unlike regular pills that you take by mouth, which can break down quickly in the stomach or not work well because they don't dissolve well, nanocomposites can keep the drug safe from digestive enzymes and acidic environments. This shield keeps the drug whole when it gets to its target spot. Nanocomposites also allow for controlled, long-lasting drug release, which helps keep beneficial drug levels steady over time, which lowers side effects and boosts drug effectiveness. They can also be made to target specific parts of the digestive system or even tissues. This makes drug delivery more precise and reduces side effects that happen outside of the intended area.

Conversely, Nano composites can be designed to launch the medication in a regulated manner through diffusion, breakdown, or stimuli-responsive mechanisms. Made to break down beneath positive physiological environments, along with the ones concerning pH or temperature fluctuations, biopolymers may this may permit medications contained at the GI system's goal site to be released [1]. Moreover stopping medicines from breaking down within the digestive tract because of enzymes or out of doors stimuli are biopolymer-based Nano composites. Before they input the movement, many medications may be damaged down in the belly by acids and enzymes there. The medicine is blanketed from breaking down on this manner by being housed interior a safe Nano composite matrix, therefore preserving it intact till it reaches the website online of absorption. These Nano composites additionally have one in addition advantage: they are able to precisely shipping medicinal drugs where they are required [2]. Usually distributed all through the frame, medicines taken orally would possibly have poor results in places not intended to be impacted. Conversely, nanocomposites may be designed to target certain GI tract segments or even tissues or systems all over the body. By varying the surface properties of the nanoparticles or using certain ligands, one may create nanocomposites that either cling to or penetrate particular cells or tissues [3]. This lowers unintended consequences and enhances the therapeutic action. Because they can store many various types of drugs including small molecules, proteins, nucleic acids, and vaccines biopolymer-based nanocomposites are quite adaptable. They are flexible; hence they may be used in different spheres of therapy.

BACKGROUND AND LITERATURE REVIEW

Traditional Oral Drug Delivery Systems

Tablets, pills, and solutions, which are traditional ways to take drugs by mouth, have been the mainstay of medicinal care for decades. Oral drugs are chosen for most medicines because they are easy to give, don't hurt, and are more convenient for the patient. But there are some things that these systems can't do. One big problem is that many drugs are not very bioavailable. Orally given drugs are less effective because they don't dissolve well, go through a lot of first-pass digestion in the liver, and break down quickly in the acidic environment of the stomach. Because of this, the amount of drug in the blood may not be high enough to have the healing effect that is wanted [4]. Also, with traditional mouth delivery, it's not always possible to control how fast the drug is released. When drugs are released right away, their concentrations rise quickly, causing drug levels in the blood to change. These changes can lead to side effects, less effectiveness, or harm, especially with drugs that only work in a small treatment

window. Traditional approaches also allow medications to be distributed all across the body as they lack customised means of transportation. This might raise the possibility of negative effects and harm of healthy tissues. The pharma industry has been searching for fresh approaches to distribute medications, such as controlled-release systems and targeted drug delivery, in order to get beyond these challenges [5]. Standard oral medication delivery techniques are still not very effective in offering the optimal drug delivery patterns even with these developments. This is why novel drug delivery techniques like nanocomposites have been developed and show promise as means of overcoming these issues.

Size and surface charge of nanoparticles are very important for how drugs are released and absorbed. Nanoparticles that are smaller have more surface area, which makes it easier for drugs to interact with them. This increases the drug's loading capacity and makes it easier for the drug to dissolve and be used by the body. The charge on the nanoparticles' surface changes how they interact with living things, like cell walls. Charges that are positive or negative can change how quickly drugs are absorbed by the body by making it easier for them to connect with certain cells or organs. For instance, nanoparticles that are positively charged might stick to negatively charged cell walls better, making it easier for cells to take them in. You can change these features to change the rate at which the drug is released, either through diffusion, breakdown, or stimuli-response processes. This makes sure that the drug gets to the right place.

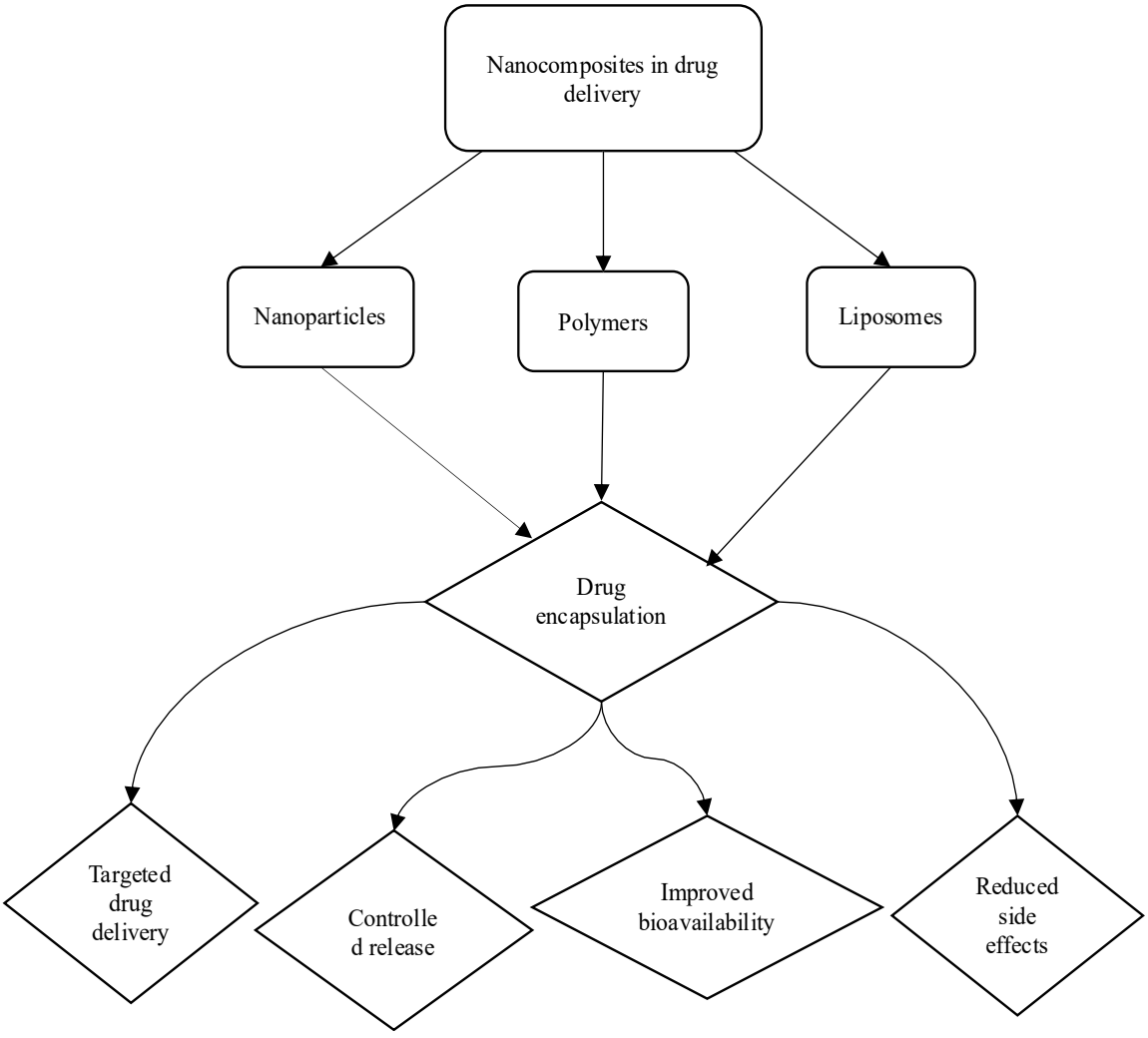

Figure 1. Illustrating nanocomposites in drug delivery.

Table 1. Summary of Background and Literature Review.

Aspect	Challenges	Future Trend	Scope
Drug Release Profile	Stability of nanoparticles during storage	Development of stimuli-responsive nanocomposites	Enhancing the predictability of drug release
Biopolymer Selection (e.g., Chitosan, Alginate)	Ensuring biopolymer compatibility with drugs	Customization of biopolymers for specific drugs	Use of biopolymers with specific drug affinity
Encapsulation Efficiency	Low drug loading efficiency in some systems	Improving drug loading capacities	Tailored formulations for improved efficiency
Targeted Delivery [11]	Difficulty in targeting specific tissues	Advances in targeting ligands and nanoparticles	Localized treatment for cancers and chronic diseases
Solubility Enhancement for Poorly Soluble Drugs	Limited solubility enhancement for hydrophobic drugs	Use of hybrid biopolymer systems for solubility	Formulation of oral drugs with low solubility
Nanoparticle Aggregation	Aggregation of nanoparticles reduces efficiency	Development of stabilizing agents	Increased efficiency in drug delivery
Safety and Toxicity Studies	Uncertainty in long-term safety of nanoparticles	Comprehensive safety evaluation protocols	Regulatory approval for clinical use
Manufacturing Scalability [12]	Difficulty in scaling up for industrial production	Continuous manufacturing systems	Industrial-scale production of nanocomposites
pH-Sensitive Biopolymers for Gastrointestinal Delivery	Variability in pH response	Engineering pH-sensitive biopolymers	Site-specific delivery in the gastrointestinal tract
Combination with Other Delivery Systems	Complexity in combining systems effectively	Integration with other drug delivery platforms	Combination with other advanced delivery systems
Biodegradability and Environmental Impact	Degradation of nanocomposites before target site	Biodegradable, eco-friendly polymers	Sustainable nanocomposites for green drug delivery
Nanocomposite Stability Over Time	Limited stability and shelf-life	Research on long-term stability mechanisms	Prolonged shelf-life for patient convenience
Clinical Application and Regulatory Approval [13]	Delays in clinical testing and approval	Streamlining clinical trials and approval processes	Faster clinical translation and patient access

Nanocomposites In Drug Delivery

Because of their unique properties, nanoparticles combined with plastics or different substances have drawn loads of hobby within the region of drug transportation. Those Nano composites offer various advantages over traditional strategies that enhance remedy transport. They help you manipulate how quickly prescribed drugs are added, dissolve pills extra conveniently, and are extra stable, as an example. The tiny size of nanoparticles will increase their surface area, consequently improving the interface between the medication and the delivery car [6]. This enables one to better seize the drugs and lift its loading potential. Either via breaking down or diffusing, or through reacting to outside variables such pH, temperature, or magnetic fields, Nano composites may be designed to launch prescribed drugs in a regulated manner. This regulated launch helps you to keep away from taking as many dosages and guarantees extended recovery outcomes [7]. Way to this safety, the medication will continue to be complete till it reaches its distinctive vicinity. Figure 1 shows cautiously synthetic Nano composites supposed to distribute medicinal drugs, for this reason enhancing the efficacy and precision of remedy.

Because the surface features of the nanoparticles can be altered to have interaction with sure cells or receptors, Nano composites can allow targeted medicine delivery. Including focused ligands or antibodies to the surface of the nanoparticles permits Nano composites which can be added to certain

areas of the frame, consisting of most cancers cells or swollen tissues, to be targeted. This diploma of sensitivity reduces pollution and enables to minimise detrimental consequences, therefore making the therapy more secure and more efficient generally. Because of these advantages, Nano composites have proven remarkable promise in diverse therapeutic fields which includes cancer, gene therapy, and vaccine distribution. Biologics, tiny molecules, biologics, and nucleic acids are some of the many remedy molecules they will convey, so they may be adaptable and appropriate for plenty various kinds of therapies [8].

Recent Advancements in Biopolymer-Based Nanocomposites

They mix the special features of nanoparticles with the advantages of natural polymers. Because they are biocompatible, biodegradable, and create non-toxic breakdown products, biopolymers like polysaccharides, proteins, and lipids are suitable for drug delivery. Since biopolymer-based nanocomposites produce little immune system issues or long-term damage, these properties make them very safe for human usage. Aiming at enhancing their drug transport capacity by including various nanoparticles, recent advancements in biopolymer-based nanocomposites [9] have to improve medication release, stability, and containment, for example, carbon-based components, liposomes, and metal nanoparticles are being included to biopolymer constructions. One may create these molecules to deliver medications gradually and safely throughout time. For medications that must be long-acting, this is particularly beneficial. Work on targeted medication administration as well as controlled release is in progress on biopolymer-based nanocomposites. Tenth [10] By altering the surface properties of the nanoparticles or applying certain ligands, one may create nanocomposites aimed at specific cells, tissues, or organs. This reduces the effects going beyond the target and increases the precision of the therapy. Table 1 summarises the connected work, challenges, future trends, and topic of the literary research.

MATERIALS AND METHODS

Selection of Biopolymers for Nanocomposite Preparation

The choice of biopolymers for creating nanocomposite is a major determinant of the performance of drug delivery systems. Natural polymers called biopolymers originate from materials that are repeatedly reusable. In many respects, including biocompatibility, biodegradability, and environmental friendliness, they surpass artificial polymers. The ideal biopolymer for a nanocomposite must possess particular characteristics that enable easy encapsulation and regulation of healing agent release while also ensuring system safety and efficiency [14]. Consider their physical properties, biocompatibility, biodegradability, and capacity to mix with nanoparticles when selecting biopolymers for nanocomposite manufacture. Many times, drug delivery devices are made from biopolymers like starch, alginate, and chitosan. Natural occurring polymer derived from chitin is chitosan. It is very appealing because it can make films, is biocompatible, and is not poisonous. Nanocomposites made of chitosan are also known to make encapsulating drugs more stable and to offer controlled release qualities, which makes them good for oral drug delivery [15]. Another polysaccharide called alginate is used a lot in drug administration because it can turn into hydrogels when calcium ions are present.

Preparation of Nanocomposites

Adding nanoparticles to biopolymer frameworks improves the qualities and usefulness of the drug delivery system. This is how biopolymer-based nanocomposites are made. Making nanocomposites can be done in a number of different ways, and each has its own pros and cons. The type of biopolymer, the characteristics of the nanocomposite that are wanted, and the type of drug that needs to be given all affect the choice of preparation method. Liquid casting is one of the most popular ways to make nanocomposites. This method dissolves the biopolymer and drug in a good liquid and then adds the nanoparticles. A stiff nanocomposite film or matrix is produced after the liquid disappears [16]. Mass manufacturing may benefit from this approach as it is cheap and simple to apply. However, the choice of solvent and the possibility of solvent residues affect the quality and safety of the produced goods. Particularly for nanofibers [17], electrospinning is another technique often utilised to produce biopolymer-based nanocomposites. This approach runs a polymer solution at high voltage. This

produces little fibres from the polymer that may subsequently be combined with nanoparticles. Making nanocomposites with plenty of surface area relative to volume is easy using electrospinning. This qualifies them for usage in controlled drug release.

Characterization Techniques

Scanning electron microscopy (SEM)

Strong imaging technique scanning electron microscopy (SEM) is used to characterise the form, size, and surface distribution of nanoparticles and Nano composites. With a focused electron beam, SEM scans the surface of the sample so that secondary and backscattered electrons are produced through material response. This produces floor high-density images. Those signals then are gathered and used to create exact 3-dimensional images of the sample's floor. Because SEM permits researchers to look the distribution of the nanoparticles in the biopolymer matrix, it's far often hired to analyze biopolymer-primarily based Nano composites. This gives them with pertinent information on the homogeneity and regularity of the composite fabric [18]. The ability of SEM to capture images with a totally excessive magnification allows one to see patterns on the micrometre and nanometre levels. This is especially important for drug transport because the shape and size of nanoparticles can change how much drug they can hold, how fast they release the drug, and how bioavailable the system is. SEM can also tell you about the structure and hardness of nanocomposites' surfaces, which can change how they interact with living things.

- *Step 1: Electron beam interaction with the sample:* The electron beam is directed at the sample, and the interaction can be described using the following equation based on electron scattering:

  $$I(E) = I_0 * \exp\left(\frac{-x}{\lambda(E)}\right)$$

  Where:
  - I(E) is the intensity of the electron beam after traveling a distance x,
  - I_0 is the initial intensity of the electron beam,
  - λ(E) is the mean free path length of the electrons, which depends on the energy of the electron beam.
- *Step 2: Detection of secondary electrons*: When the electron beam interacts with the sample, secondary electrons are emitted. The number of secondary electrons detected can be given by:

  $$N_{SE} = \alpha * I(E) * \Omega$$

  Where:
  - N_SE is the number of secondary electrons emitted,
  - α is a material-dependent efficiency factor for secondary electron generation,
  - Ω is the solid angle of the detector.
- *Step 3: Resolution and image formation*: The resolution (R) of the SEM depends on the beam size and the interaction volume, which is related to the electron beam current and the geometry of the system:

  $$R = \frac{1}{(\sigma * I_{beam})}$$

- *Step 4: image scaling*: The image scaling in SEM can be calculated by considering the electron interaction and the sample-to-detector distance. The scaling factor (S) is given by:

  $$S = \frac{D_{sample}}{D_{detector}}$$

FOURIER TRANSFORM INFRARED SPECTROSCOPY (FTIR)

Popular method of determining the chemical shape and useful organizations of biopolymer-primarily based Nano composites is FTIR, or Fourier remodel Infrared Spectroscopy. The FTIR method gauges a sample's absorption of infrared light. This radiation begins unique frequency motions of molecules [19]. The spectrum displays the chemical composition and interactions a few of the biopolymer, nanoparticles, and encapsulated drugs. These waves are specific for positive chemical bonds and

practical organizations in the pattern. Concerning Nano composites, FTIR is especially beneficial for investigating the interactions among the biopolymer matrix and the nanoparticles and for making sure that medicines were successfully covered to the Nano composite. Normally showing bands corresponding to the functional groups of the biopolymer, nanoparticles, and every other additional aspect which includes medicines or stabilizers the FTIR spectrum of a Nano composite generally famous must those points vary in power or motion, it might imply that covalent connections, electrostatic interactions, or hydrogen bonds are occurring among the pieces.

- *Step 1: Mathematical description of infrared absorption*: The infrared absorption by a molecule can be described as:

  $$A(\omega) = \int I(\omega)\ \varepsilon(\omega)\ c(\omega)\ ds$$

- *Step 2: Fourier transform of the time domain signal*: FTIR works by performing a Fourier transform of the time-domain signal to obtain the frequency-domain spectrum:

  $$S(\omega) = \int s(t) * e^{-i\omega t} dt$$

- *Step 3*: *Conversion of interferogram to absorbance spectrum*: The interferogram obtained from FTIR is converted into an absorbance spectrum using the relation:

  $$A(\omega) = -log10\left(\frac{I(\omega)}{I_{0(\omega)}}\right)$$

Applications of Biopolymer-Based Nanocomposites in Oral Drug Delivery

Drug targeting and controlled release

By adding specific ligands, antibodies, or other targeted agents to the surface of the nanoparticles, nanocomposites may be designed to preferably collect at the region of interest, such a cancer or swelling tissue. Targeted nanocomposites may help medications taken orally reach the pharmaceuticals exactly where they need to go in the gastrointestinal (GI) tract or even to specific regions throughout the body. pH-sensitive biopolymers may be created, for example, to release their therapeutic content in the acidic environment of the stomach or at certain pH levels in the intestines. This guarantees that the medicine reaches its target without disintegrating too rapidly [20].

Biopolymer-based nanocomposites have been used successfully to deliver different kinds of drugs, such as vaccines, small molecules, proteins, and nucleic acids. For example, hydrophobic drugs that don't dissolve well or stay stable in the digestive system can be put inside biopolymer nanocomposites to make them more bioavailable and dissolve better. These nanocomposites have also been used for guided transport in cancer treatment, which means that drugs are sent only to tumour areas [21]. Adding metal or carbon nanoparticles, like graphene oxide, to biopolymer structures has been shown to improve the transport and efficiency of drugs used to treat cancer.

Enhancing Bioavailability and Stability of Drugs

Biopolymer-based nanocomposites could be a good way to solve this problem because they make drugs more stable, soluble, and absorbable. A lot of drugs don't dissolve well in water, which makes it harder for the body to take them in the GI system. This makes the drugs less bioavailable. By adding these drugs to biopolymer-based nanocomposites, their solubility can be greatly improved [22]. This is because nanoparticles can speed up the dissolving rate of drugs that don't dissolve easily, which leads to better absorption and better healing benefits. Figure 2 shows how new formulations and methods can be used to make drugs more bioavailable and stable.

It is known that biopolymers like chitosan, alginate, and gelatin can create safe structures that keep drugs inside from breaking down because of things in the environment like pH changes, enzymes, or oxidative stress. This is very important for medicines that don't like the acidic environment of the stomach or the digestive enzymes in the bowels. By placing these drugs inside biopolymer structures, they are protected from breaking down. This keeps them whole and working until they reach their absorption spot.

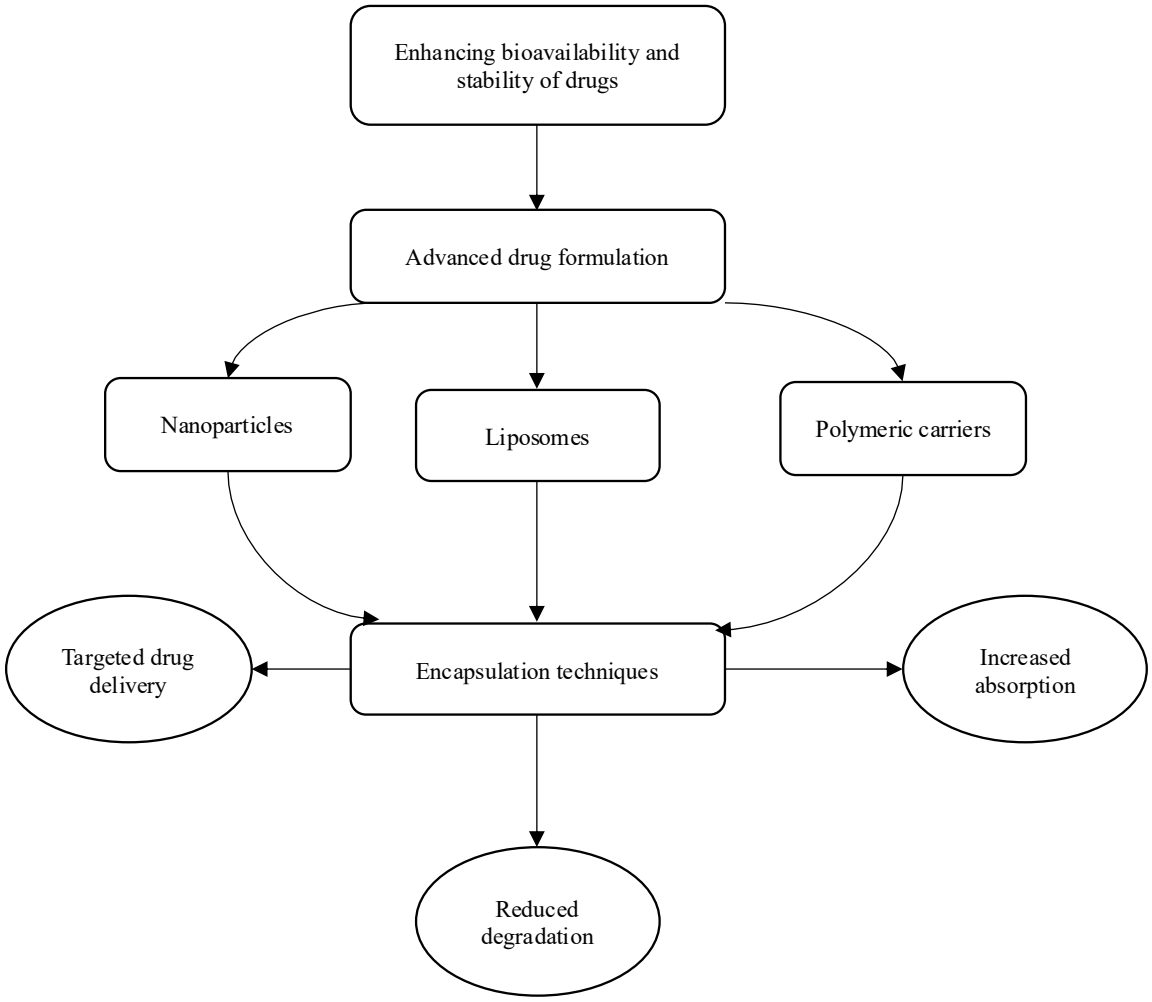

Figure 2. Illustrating enhancing bioavailability and stability of drugs.

Challenges in Oral Drug Delivery Using Biopolymer-Based Nanocomposites

Stability and shelf-life of nanocomposites

It's hard to make biopolymer-based nanocomposites that are stable and last a long time. This makes them less useful for oral drug delivery. Naturally occurring substances like biopolymers can break down in a number of situations, such as when the temperature, humidity, or light levels change. Biopolymer structures that break down can cause the drug to be released too early, which lowers the controlled release profile that is needed for drug delivery to work? Also, when the biopolymer and drug combine, it can make the drug less stable. This is especially true for sensitive drugs that are easily broken down by oxidation, hydrolysis, or enzymes [23]. Nanocomposites by their very nature also provide challenges regarding the stability of the nanoparticles mixed in with the biopolymer matrix. Because nanoparticles may clump together, their ability to enclose and release medications may be decreased. Important for ensuring that the drug release patterns are always the same is homogeneity and regularity of the nanocomposite, which may also differ depending on this sticking together.

Manufacturing Scalability

A big problem in making biopolymer-based nanocomposites for oral drug delivery is that they can't be made on a large scale. Nanocomposites have been made on a small scale in the lab for a long time, but putting these methods to use in large-scale production is hard from both a technical and an economic point of view. The ability to regularly make nanocomposites with uniform size, drug loading, and release profile is one of the most important problems. When nanoparticles are different sizes and spread out in different ways, they can give drugs in different ways, which is not accepted in pharmaceutical

uses. Some of the ways that biopolymer-based nanocomposites are made, like liquid casting, electrospinning, and coacervation, may be scalable in theory, but they can be hard to get right for mass production. For instance, solvent evaporation methods can produce different results from batch to batch because the rates at which the solvent evaporates vary. On the other hand, to make uniform nanofibers, electrospinning needs precise control over external conditions like humidity and temperature. Also, adding nanoparticles to biopolymer materials needs to be carefully managed so that the nanoparticles don't stick together or spread out poorly, which could affect the quality of the end product. One problem with making the manufacturing process bigger is that it needs special tools and places to work. To make biopolymer-based nanocomposites, you may not be able to find new tools in normal industrial settings. Large-scale production of these nanocomposites can be expensive because of the need for specialised tools and complicated processes. This could make them less useful in the business world.

RESULT AND DISCUSSION

Biopolymer-based nanocomposites showed a lot of promise for improving the transport of medicinal drugs through the mouth. The SEM and TEM tests showed that the nanoparticles were successfully mixed into the biopolymer matrixes, showing that they were evenly distributed and the same size. The FTIR spectrum showed that the biopolymer and nanoparticles were steady together, which proved that the drug was successfully encapsulated. Controlled drug release patterns were seen in in vitro tests, which suggests that biopolymer-based nanocomposites can keep drug release going for a long time.

The drug release profile of the biopolymer-based nanocomposites shown in Table 2 shows that the three different versions have different release profiles. The release rate for Nanocomposite 2 is 18.4% after one hour, followed by Nanocomposite 1 (15.2%) and Nanocomposite 3 (12.5%). Figure 3 shows how the release patterns of nanocomposites change over time and how drugs are delivered over a long period of time.

Table 2. Drug Release Profile of Biopolymer-Based Nanocomposites.

Time (hrs)	Nanocomposite 1 release (%)	Nanocomposite 2 release (%)	Nanocomposite 3 release (%)
0	0	0	0
1	15.2	18.4	12.5
3	34.5	40.2	30
5	52.3	60.1	48.6
8	72.4	78.9	69.5

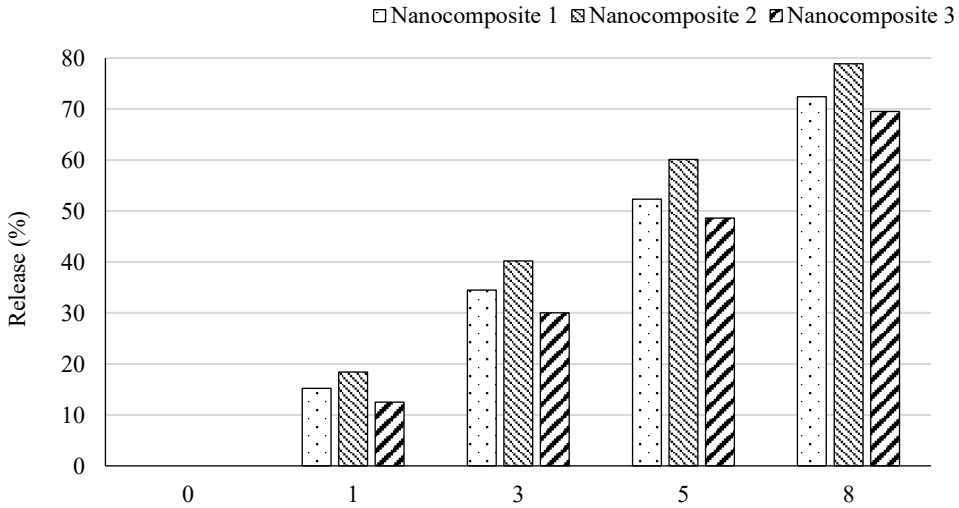

Figure 3. Comparative release of nanocomposites over time.

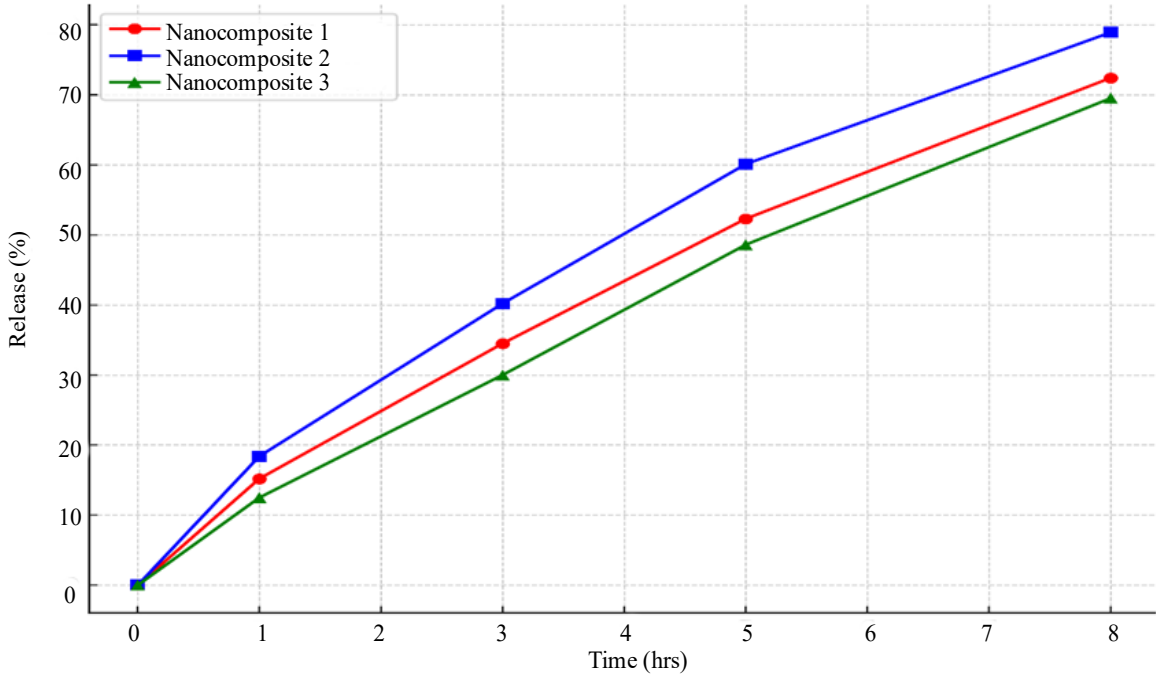

Figure 4. Time-dependent release profiles of nanocomposites.

Table 3. Encapsulation Efficiency and Stability of Biopolymer-Based Nanocomposites.

Nanocomposite	Encapsulation efficiency (%)	Drug stability after 30 days (%)	Drug stability after 60 days (%)
Nanocomposite 1	87.2	91.5	88.3
Nanocomposite 2	92.6	95.3	92.1
Nanocomposite 3	84.9	89.7	85.5

Nanocomposite 2 always has a faster drug release rate, and this trend stays the same as the release percentage goes up over time. Nanocomposite 2 releases 40.2% after 3 hours, while Nanocomposite 1 releases 34.5% and Nanocomposite 3 releases 30%. This shows that Nanocomposite 2 is made to release more quickly. The release patterns of nanocomposites change over time, as shown in Figure 4. This shows that the drug release is prolonged and managed.

Nanocomposite 2 has a 60.1% success rate after 5 hours, while Nanocomposite 1 has a 52.3% success rate and Nanocomposite 3 has a 48.6% success rate. The difference between the formulas keeps growing. This means that Nanocomposite 2 might work better for uses that need to release drugs more quickly. Nanocomposite 2 releases 78.9% of its total amount at 8 hours, while Nanocomposite 1 releases 72.4% and Nanocomposite 3 releases 69.5%.

The stability and embedding efficiency numbers in Table 3 give us important information about how well three biopolymer-based nanocomposites work. Nanocomposite 2 has the best encapsulation rate, at 92.6%, which means it does a great job of putting the drug inside the nanocomposite matrix and keeping it there. This better ability to encapsulate could lead to more effective drug administration, since more of the active medicinal ingredient is free to be released. Figure 5 illustrates encapsulation efficiency and drug stability trends across different nanocomposites over time.

Nanocomposite 2 also does better than the other two versions when it comes to drug safety. 95.3% of its drug safety is still there after 30 days, and 92.1% is still there after 60 days. Figure 6 shows how the stability and sealing efficiency of different nanocomposites for optimisation are compared.

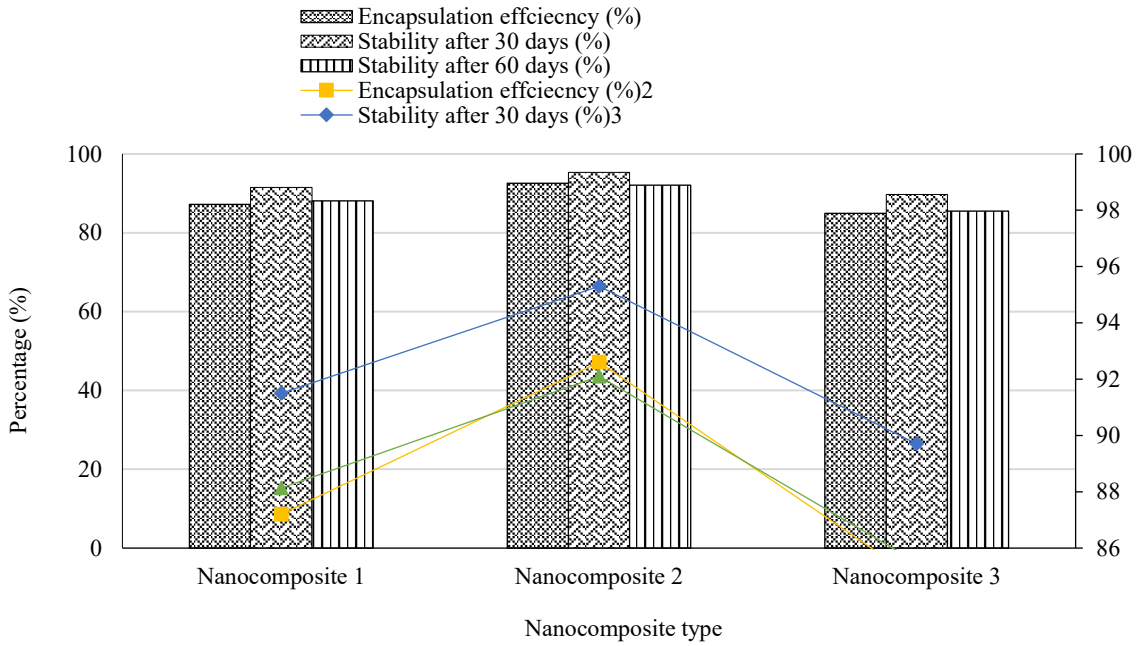

Figure 5. Encapsulation efficiency and drug stability trends across nanocomposites.

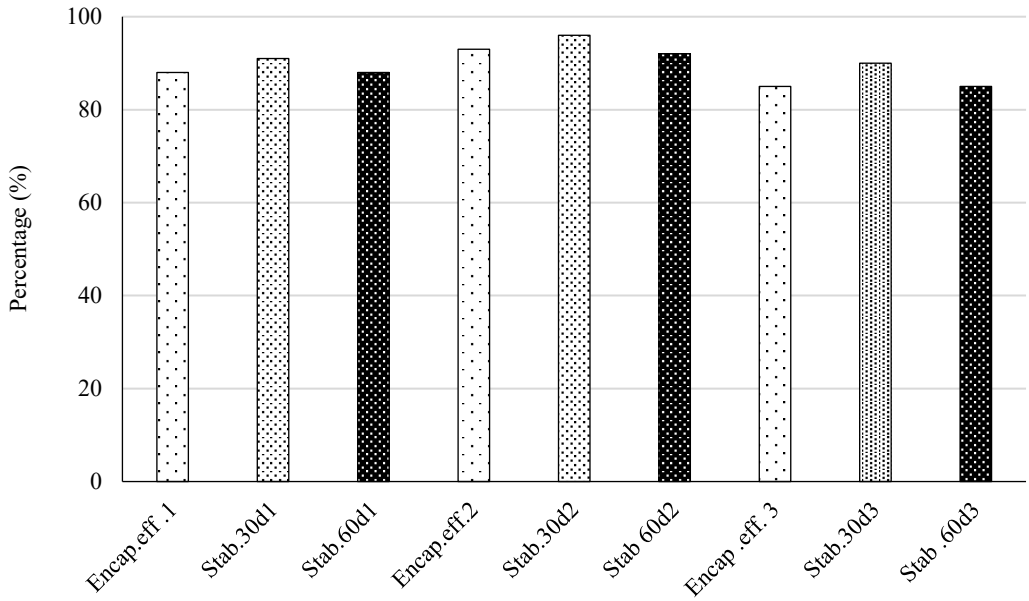

Figure 6. Comparative drug stability and encapsulation efficiency breakdown.

This means that Nanocomposite 2 is very good at keeping itself from breaking down over time, which means it can be used for long-term storage and continued drug release. The drug security of Nanocomposite 1, on the other hand, goes down slightly over time. After 30 days, it's only 91.5% stable, and after 60 days, it's only 88.3% stable. Nanocomposite 3 has the lowest encapsulation efficiency, at 84.9%, and its drug stability decreases the most, which means it does a worse job of keeping the drug from breaking down overall.

CONCLUSION

Biopolymer-based nanocomposites are a potential way to make oral drug delivery methods better, and they have a number of benefits over traditional drug formulations. Because they are biocompatible,

biodegradable, and can hold a lot of different drugs, these nanocomposites can be used in many medicinal situations. Biopolymer-based nanocomposites can release drugs slowly and steadily, which is one of their best features. This is very helpful for drugs that have a short half-life or a small therapeutic window because it makes therapeutic amounts steadier and reduces side effects. Biopolymer-based nanocomposites can also make drugs that don't dissolve well more bioavailable and stable. The addition of nanoparticles helps to make the drug's surface area bigger, which speeds up its breakdown and uptake in the digestive system. The protective structure of the biopolymer matrix also keeps drugs from breaking down in the environment due to things like gut acids or digestive enzymes until they get to where they need to go to be absorbed. One more big benefit is that drugs can be delivered precisely where they are needed. Nanocomposites can be made to carry drugs more efficiently to certain tissues or organs by changing the surface qualities of nanoparticles. This improves the healing effect while lowering the number of side effects that happen outside of the target area. This focused method can be especially helpful when treating diseases like cancer, where delivering drugs directly to the tumour can make treatment more effective while causing less harm to good cells.

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