RESEARCH PAPER

Cellulose-Based Drug Carriers: A Sustainable Approach

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ABSTRACT
A possible fresh concept in the realm of medication delivery systems is cellulose-based drug carriers. Unlike usual artificial carriers, they are biodegradable and beneficial for the environment. One naturally occurring fiber with great advantages is cellulose, derived from plants. It is easily found, biodegradable, not harmful. This essay examines many therapeutic contexts in which cellulose may be employed as a medication carrier. It discusses its attributes, how it may be altered, and how it might retain medications. Different modifications like esterification, etherification, and nanofibrillation can be done to cellulose to increase its drug-loading capacity and modulate drug release rates by means of flexibility. Making many kinds of cellulose carboxymethyl cellulose (CMC), hydroxypropyl cellulose (HPC), and cellulose nanocrystals (CNC) is made simpler by these developments. Every one of these has unique features that make them valuable for various drug transportation chores. Cellulose is an excellent choice for controlled release formulations since its changing surface chemistry also makes it superior at targeting pharmaceuticals and maintaining their stability. Moreover, cellulose-based drug carriers can be combined with other safe polymers and nanoparticles to enhance the drug packing process and thus the outcomes of treatment. Because they can be produced to do more than one thing and react to things like pH, temperature, and enzymes, cellulose-based carriers find application in many more spheres of personalized medicine. Cellulose is also reusable and is utilized again and over. For pharmaceutical firms aiming to be more environmentally friendly by utilizing less nonrenewable resources and reducing the impact of medicine delivery techniques on the surroundings, this makes it a wise decision

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INTRODUCTION

Pharmacists scientists need more long-lasting solutions amid growing concerns about the harm produced goods do to the environment. Natural, recyclable materials for medication delivery systems have so been investigated. Naturally present in plants, cellulose is a fibre that has attracted a lot of interest as a perfect substance for safe pharmaceutical carriers for human cells and the surroundings. Among the most often occurring natural polymers on Earth is cellulose. It is less expensive than synthetic polymers often utilised in the pharmaceutical industry and may be used again. Cellulose-based drug carriers should be able to satisfy both the demand for efficient medication delivery and the aim to make therapeutic items less detrimental to the environment as people search for alternatives that are better for the environment. Comprising glucose units joined by β-1,4-glycosidic linkages, cellulose is a polymer. Good for various drug transportation applications, these components provide a straight chain structure. Among these are biocompatibility, non-toxicity, biodegradability, and chemical modification capability to improve performance. Because it has a high surface area, considerable mechanical strength, and can be rapidly transformed into other forms—such as films, gels, fibres, and nanoparticles—cellulose is a useful medium for transporting pharmaceuticals. The fact

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that cellulose-based drug carriers may be physically and chemically altered to meet the demands of various drug transport environments is their greatest advantage. Chemical modifications such as esterification and etherification enable the creation of cellulose products better at dissolving, transporting medicines, and regulating their release. For instance, hydroxypropyl cellulose (HPC) and carboxymethyl cellulose (CMC) have been extensively investigated as they can make medications more soluble and enhance their release mechanism. Furthermore improving the efficacy of medication transport and packaging are cellulose nanoparticles such as cellulose nanocrystals (CNC) and cellulose nanofibrils (CNF). Apart from its chemical modifications, cellulose may be applied in other ways to regulate the medication release.

Drug release in response to certain environmental events—such as pH, temperature, or enzyme breakdown—can be achieved with cellulose-based carriers. This makes them ideal for getting narcotics to particular places. Flexible tailored medication delivery techniques allow one to create treatments that lower side effects and increase therapy outcomes. Adding additional appropriate components to cellulose-based containers—such as lipids, proteins, or nanoparticles—improves the safety, absorption, and efficiency of the medications within as well. One of the better features of cellulose-based drug carriers is their biodegradability. Unlike many synthetic polymers, which persist in the environment and damage ecosystems, cellulose-based transporters break down organically into benign byproducts. This function aligns with the growing trend of "green" medications, which aim to reduce waste, energy consumption, and dependency on resources unable of replacement [1]. This makes cellulose-based drug carriers not only hopeful for bettering patient outcomes but also a long-term solution for the issues that conventional drug delivery systems bring about. Thanks primarily to nanotechnology and material science, cellulose-based drug delivery techniques have advanced over the past few years.

RELATED WORK

Cellulose-based totally drug providers have attracted a lot of interest currently as they're environmentally pleasant, well suited with residing entities, and may be chemically altered to launch medicines in a targeted and below manage technique. Many studies have investigated how great to apply cellulose merchandise, nanocrystals, and nanofibrils as powerful drug companies. 2 essential subjects of research with an awful lot of research to be completed are solubility and drug-loading capacity of cellulose. Two commonplace kinds of cellulose that have confirmed fulfillment in drug delivery programs are hydroxypropyl cellulose (HPC) and carboxymethyl cellulose (CMC). Since CMC may be used to create hydrogels, which assist to adjust remedy release [2], a number of take a look at has been executed on this molecule. Research has indicated, for example, that CMC-based totally hydrogels can reduce unfavorable results and enhance the efficacy of chemotherapeutic medications. Further, HPC has been investigated for its capacity to produce medicinal drugs that do not dissolve nicely in water greater stable and soluble, consequently improving their bioavailability in drug transport structures taken by mouth. Nanocellulose which accommodates cellulose nanocrystals (CNC) and cellulose nanofibrils (CNF) has additionally attracted quite a few observes. Among other matters, it has incredible mechanical power, plenty of floor region, and biocompatibility [3].

CNC and CNF may additionally efficaciously maintain hydrophobic prescribed drugs, according to studies, which increase the steadiness and ease of the medicines with the aid of this asset. With regulated launch quotes, numerous tablets which include medicines and cancer-fighting tablets were carried on nanocarriers constructed with CNC. The small particle length and huge floor region of CNC also assist cells to take in medications and distribute them to the ideal web sites, consequently enhancing the efficacy of treatment. Furthermore, companies primarily based on cellulose can be designed to reply to sure environmental factors inclusive of pH, temperature, and enzymes. This qualifies them ideal for delivering medicines just to the proper region [4]. Making drug carriers suitable for localized therapies has been much facilitated by this ability. As an example, cellulose-based nanoparticles that are sensitive to pH have been created to send drugs specifically to the digestive system, where the pH changes a lot. These carriers make sure that drugs are only released in certain places, which lowers the risk of side effects and exposure to the whole body

Table 1: Summary of Related Work

Related Work	Future Trends	Benefits	Challenges
Use of carboxymethyl cellulose (CMC) for controlled release	Development of multi-functional cellulose-based carriers	Biodegradable and eco-friendly	Limited mechanical strength of certain cellulose forms
Encapsulation of anticancer drugs using cellulose nanoparticles [5]	Targeted drug delivery using modified cellulose	Biocompatibility and low toxicity	Difficulty in scaling up production
Hydroxypropyl cellulose (HPC) for oral drug delivery systems	Advanced stimuli-responsive cellulose carriers	Can encapsulate a wide range of drugs	Variability in drug release rates based on formulations

Cellulose nanocrystals (CNC) for improved drug stability	Combination with nanotechnology for better drug encapsulation	High drug-loading capacity and stability	Inconsistent drug release in some formulations
Use of cellulose derivatives for sustained release formulations [6]	Increased use in personalized medicine	Ability to improve bioavailability of poorly soluble drugs	Challenges in achieving uniform drug distribution
Development of cellulose-based hydrogels for injectable formulations	Biocompatible and non-toxic cellulose nanofibers in drug carriers	Renewable and abundant material source	Issues with long-term stability of hydrogels in vivo
Combination of cellulose with other polymers for controlled release	Smart drug carriers responding to pH, temperature, or enzymes	Reduced environmental impact	Limited ability to achieve precise targeting
Topical drug delivery using cellulose-based carriers for skin diseases [7]	Expansion into chronic disease treatment via cellulose systems	Low environmental impact and sustainability	Potential for skin irritation with some formulations
Development of cellulose nanocomposites for enhanced drug delivery	Integration of cellulose with AI for drug release optimization	Simple and low-cost manufacturing	Possible toxicity of modified cellulose in certain contexts
Cellulose-based delivery for antibiotics and wound healing	Increasing use in vaccines and biologic drug formulations	Potential for reduced side effects and systemic exposure	Regulatory challenges for novel materials
Clinical trials using cellulose-based systems for drug delivery [8]	Hybrid cellulose-based carriers for multi-drug delivery	Potential for environmentally friendly, sustainable solutions	Lack of standardized production methods

MECHANISMS OF DRUG RELEASE

A. Encapsulation and loading methods

Encapsulation is a very important step in the process of making cellulose-based drug delivery methods. It's the process of putting a drug inside a host material, like cellulose, to keep it from breaking down, make it easier to dissolve, and control how much of it is released. Drugs can be enclosed in cellulose-based devices in a number of ways, such as through chemical bonds, physical trapping, and liquid release. One of the easiest and most common ways to encapsulate drugs is to trap them physically [9]. Figure 1 displays packaging techniques and different loading methods that make working and sending data faster

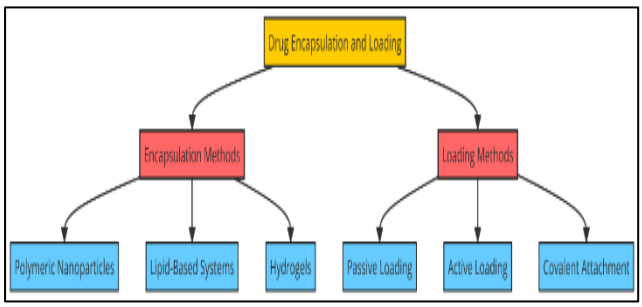

Figure 1: Illustrating Encapsulation and Loading Methods

In a fluid or slurry, the drug is mixed with cellulose products like carboxymethyl cellulose (CMC) or hydroxypropyl cellulose (HPC). The drug is then trapped inside the cellulose framework while nanoparticles or hydrogels are being made. This approach is simple to apply, scalable, and devoid of any harmful chemicals or liquids, so it is beneficial. Conversely, chemical bonding is the mechanism by which pharmaceuticals are coupled to the cellulose transportation by chemical reactions. This technique guarantees that medications are surrounded in a more solid and robust shell. For medications impacted by factors like light and temperature, this is particularly beneficial [10]. Like esterification or etherification, chemical modifications to cellulose can provide functional groups that enable the medication to better attach to the host material. This increases the drug's release quality and helps it to be more stable. Solvent evaporation is another often used method to incorporate hydrophobic compounds into cellulose frameworks. Under this approach, a medication and cellulose product mix together in an organic liquid. After that, the solvent is taken out, leaving solid bits with the medicine. Hydrophobic drugs can be managed enclosed in this method, as they might be hard to put into cellulose-based transports otherwise.

- Step 1. Drug Loading Efficiency (DLE)

This represents the amount of drug successfully loaded into the carrier. It is calculated using the following equation:

$$DLE\ (\%) = \left(\frac{Amount\ of\ Drug\ Loaded}{Total\ Amount\ of\ Drug\ Used\ for\ Loading}\right) * 100$$

Where:
- Amount of Drug Loaded refers to the quantity of drug found in the carrier after encapsulation.
- Total Amount of Drug Used is the initial drug quantity before encapsulation.

- Step 2. Encapsulation Efficiency (EE)

Encapsulation Efficiency represents the proportion of drug encapsulated in the carrier relative to the total drug added. It is calculated as:

$$EE\ (\%) = \left(\frac{Amount\ of\ Drug\ Encapsulated}{Amount\ of\ Drug\ Initially\ Added}\right) * 100$$

Where:
- Amount of Drug Encapsulated is the amount of drug successfully trapped inside the carrier.
- Amount of Drug Initially Added is the total drug added to the carrier before encapsulation.

- Step 3. Cumulative Drug Release (CDR)

The Cumulative Drug Release over time represents the total amount of drug released from the carrier. It is generally modeled by the equation:

$$CDR\ (\%) = \left(\frac{Amount\ of\ Drug\ Released\ at\ Time\ t}{Total\ Amount\ of\ Drug\ Loaded}\right) * 100$$

Where:
- Amount of Drug Released at Time t is the amount of drug released at a specific time.
- Total Amount of Drug Loaded refers to the drug initially encapsulated in the carrier.

- Step 4. Release Kinetics: Zero-Order Release Model

The release of drug from cellulose-based carriers often follows a zero-order release, where the release rate is constant over time. The equation for zero-order kinetics is:

$$Q\_t = Q\_0 + k\_0\, t$$

Where:
- Q_t is the amount of drug released at time t,
- Q_0 is the initial amount of drug in the carrier,
- k_0 is the zero-order rate constant,
- t is the time elapsed.

- Step 5. First-Order Release Kinetics

In many cases, drug release follows a first-order kinetic model, where the drug release rate is proportional to the concentration of the drug remaining in the carrier. The equation is:

$$ln\left(\frac{C_0}{C_t}\right) = k_1 t$$

Where:
- C_0 is the initial concentration of the drug in the carrier,
- C_t is the concentration of the drug at time t,
- k_1 is the first-order release constant.

B. Controlled release mechanisms

Because they allow medications to remain in the body for a long period, therefore improving therapeutic efficacy and lowering adverse effects, controlled release techniques are extremely vital in drug delivery systems. Diffusion, disintegration, and growth are just a few of the several ways controlled release may be attained in cellulose-based drug carriers. Diffusion-based release is among the most often used mechanisms by which cellulose-based drug carriers function. During this procedure, the drug gradually exits the transport system and enters the environment [11]. Factors include the stability of the drug molecules, their size, and the amount of holes in the cellulose transport influence the rate of diffusion. The controlled release profile can be altered by varying the molecular weight of cellulose products or the method of encapsulation for the medication.

For instance, high binding density cellulose-based hydrogels or nanoparticles help to slow down the drug's movement and increase its lifetime. Degradation-based release is still another crucial method of regulating medication distribution. Under this approach, the body breaks down the cellulose transporter under regulated levels either by hydrolysis or enzyme activity. This helps the medication within gradually come out [12]. For example, cellulose acetate or carboxymethyl cellulose can be broken down in response to specific environmental elements such as pH or temperature. This approach helps the medicine to be released exactly and at the correct location. This guarantees correct location and safe release of the medicine. Another effective method of delivering cellulose-based medications is by swelling-regulated release. Like CMC, hydrophilic cellulose derivatives may absorb water and swell. This helps the medication within gently emerge [13]. Since the medicine is released when water or bodily fluids are present, this technique performs exceptionally effectively for oral drug distribution. Changing the kind and amount of cellulose used will help to the rate of drug release can be fine-tuned by changing how cellulose structures grow.

- Step 1. Zero-Order Release Kinetics

The zero-order release model is used when the drug is released at a constant rate over time. The mathematical equation for zero-order kinetics is:

$$Q\_t = Q\_0 + k\_0\, t$$

Where:
- Q_t = Amount of drug released at time t,
- Q_0 = Initial amount of drug in the system,
- k_0 = Zero-order rate constant,
- t = Time elapsed.

- Step 2. First-Order Release Kinetics

In first-order release, the drug release rate is proportional to the remaining amount of drug in the system. The equation for first-order kinetics is:

$$ln\left(\frac{C_0}{C_t}\right) = k_1 t$$

- Step 3. Higuchi Model (Diffusion-Controlled Release)

The Higuchi model is often used to describe drug release from solid matrices, where the release is primarily controlled by diffusion. The equation is:

$$Q_t = \sqrt{kt}$$

- Step 4. Hixson-Crowell Model (Cube Root Law)

This model is used to describe the release of drugs from spherical matrices where the release is controlled by particle size reduction. The equation is:

$$\left(\frac{W_0^1}{3} - \frac{W_t^1}{3}\right) = k_H t$$

- Step 5. Korsemeyer-Peppas Model (Power Law)

The Korsmeyer-Peppas equation is commonly used for drug release from polymer matrices, which is controlled by both diffusion and erosion. The equation is:

$$\frac{M_t}{M_\infty} = k\, n\, t^n$$

C. Targeted drug delivery using cellulose-based systems

Targeted medication delivery seeks to send therapeutic agents directly to where they need to go to operate effectively, therefore lowering side effects that impact the whole body and improving therapeutic outcomes. Cellulose-based drug carriers are excellent for targeted application as they are biocompatible, biodegradable, and changeable for site-specific release. There are several ways to convey medications to certain locations utilising cellulose-based systems: surface modification makes it more helpful, or outside stimulation. By altering the surface of cellulose-based carriers, one can improve their targeting of particular cells or tissues. Adding functional groups or ligands to the surface of cellulose nanoparticles allows one to create carriers that just attach to receptors on the surface of target cells. Attaching monoclonal antibodies, peptides, or other targeted ligands to cellulose nanocrystals (CNC), for example, will let the medication gather just in certain tissues, such as cancer cells. This approach ensures that the medicine only reaches the correct location, therefore reducing the adverse effects risk and improving the effectiveness of the therapy. Including stimuli-responsive components into cellulose-based systems improves their drug delivery capacity to certain locations [14]. For instance, sensitive to pH cellulose nanoparticles can be developed to release medications selectively in the digestive system or the acidic environment of tumour cells. Temperature-sensitive cellulose carriers can similarly release medications at specific sites when the body's temperature varies. Combining many stimuli-responsive systems into a single cellulose capsule allows one to exactly regulate the medication release process. This guarantees that medications reach the correct locations and at the proper moment. Additionally employed to control drug release from cellulose-based vehicles are outside influences such magnetic fields or ultrasonic waves. An outside magnetic field allows one to guide magnetic nanoparticles incorporated into cellulose fibres to the desired spot. This lets one transmit medications just to the correct location [15]. By altering the physical features of the material—such as making it grow or break—ultrasounds may also be used to release pharmaceuticals from cellulose capsules. These new focussed delivery techniques provide fascinating new opportunities for tailored medicine, therefore improving the efficacy of therapies and reducing the need for more intrusive approaches.

APPLICATIONS OF CELLULOSE-BASED DRUG CARRIERS

A. Oral drug delivery systems

Because they are biocompatible, biodegradable, and can control drug release, cellulose-based drug carriers have shown a lot of promise in oral drug delivery methods. One of the best things about using cellulose to give drugs by mouth is that it can be used to make hydrogels or nanoparticles that protect drugs from the acidic environment of the stomach and make sure they are released slowly and safely in the gastrointestinal (GI) system. Cellulose derivatives, like carboxymethyl cellulose (CMC) and hydroxypropyl cellulose (HPC), are often used in these situations because they can make medicines that don't dissolve well in water more stable and soluble, which increases their absorption [16]. Cellulose can be made into different dose forms for oral drug delivery methods, such as pills, capsules, and controlled-release formulas. For instance, cellulose-based hydrogels are used to make systems that release drugs slowly over a long period of time. This lowers the number of times a patient needs to take their medicine and increases their cooperation. Figure 2 shows a number of different ways that drugs can be taken by mouth for controlled release and specific treatment action

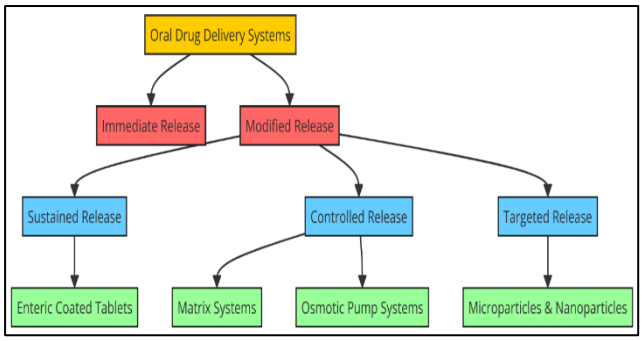

Figure 2: Illustrating Oral Drug Delivery Systems

Changing the amount of crosslinking in cellulose structures or adding pH-sensitive cellulose derivatives that release the drug when they reach acidic or alkaline conditions in the GI tract are two ways to achieve this controlled release. Also, cellulose-based carriers can be used to carry drugs specifically to certain parts of the digestive system. For example, cellulose nanoparticles can be modified to target specific receptors in the gut so that drugs are released only there. This makes them perfect for treating inflammatory bowel disease (IBD). It is possible to make cellulose-based devices that release drugs in a controlled and site-specific way. This makes sure that the drugs work better and have fewer side effects.

B. Injectable formulations

Many people administer injectable forms of medications to their bodies, particularly those that must be promptly absorbed or cannot be administered correctly via mouth. Because they may store many different medicinal substances and release them gradually over time, cellulose-based drug carriers have shown great promise in injectable medication formulations. Made to release medications gradually over an extended period of time, injectable cellulose-based systems including hydrogels, microparticles, and nanoparticles can be created Patients are thus more comfortable and do not have to receive as many injections. The fact that cellulose is biocompatible and biodegradable makes employing it in injectable goods among the better options. This implies that it breaks down safely in the body and has no negative consequences. For injectable medicines, for example, cellulose derivatives such methylcellulose (MC) and carboxymethyl cellulose (CMC) are widely utilised as they may keep the medication inside a gel-like structure and regulate how it releases.

For proteins, peptides, and other biologics that require to be released gradually over time or are readily broken down, these combinations perform remarkably. Moreover, injectable cellulose-based products can be developed to respond to certain external conditions as pH, temperature, or ionic strength. This allows one to design devices releasing medications in a regulated manner when they target particular organs or tissues. For example, pH-sensitive cellulose nanoparticles can be designed to release their material in the acidic surroundings of cancer or stomach cells. This increases the effectiveness and precision of the medicine. Injectable devices made of cellulose combined with other safe polymers or nanoparticles provide even more stability, bioavailability, and fast release of the medication.

C. Topical drug delivery

Mostly to treat skin illnesses, aid in wound healing, and route medications to the region where they are most required, cellulose-based drug carriers have also been applied in topical drug delivery systems. Because it is biocompatible, biodegradable, and easily formed into films or creams, coir is a fantastic component for cosmetic goods. Active components can be delivered straight to the skin using techniques derived from cellulose. Minimal systemic absorption and regulated release made possible by this help to reduce adverse effects by means of their respective mechanisms. Cellulose replacements such carboxymethyl cellulose (CMC), hydroxypropyl cellulose (HPC), and microcrystalline cellulose (MCC) abound in topical applications including lotions, gels, and ointments. These substances are known to produce hydrophilic structures with great water-holding capacity. Maintaining the moist skin and facilitating the absorption of active components depend on this. Moreover, products based on cellulose can be designed to release the medication gradually over an extended length of time. This guarantees that the active component stays on the skin for a lengthy period of time, which is especially beneficial for scars or long-term skin problems healing. Furthermore, topically applied cellulose-based drug carriers may be engineered to respond to outside variables as pH changes or skin temperature. Sensitive smart systems can be developed to only release medications when required.

SUSTAINABILITY AND ENVIRONMENTAL IMPACT

A. Eco-friendly aspects of cellulose-based carriers

Realising that cellulose-based medicine carriers are environmentally friendly is more and more individuals. This makes them a viable option for synthetic polymers sometimes utilised in medicine delivery systems. Cellulose is readily available and recyclable as it comes from natural sources include farming trash, cotton, and wood. For the earth, this makes it far better than products derived from petroleum. Cellulose-based carriers leave extremely minimal harm to the environment as they break down naturally into non-toxic byproducts. This is quite unlike synthetic plastics, which may remain in the environment for a long period and contribute to trash accumulation and pollution. In keeping with the concepts of the cycle economy, cellulose may also be produced from resources that can be repeatedly utilised. While many produced plastics originate from fossil fuels, cellulose comes from plants and is reusable again. For purposes of pharmaceutical transportation, this makes it a more ecologically friendly option.

Furthermore better for the environment are cellulose-based carriers since they require less energy and fewer dangerous chemicals than some produced choices. Many various drug delivery techniques including films, hydrogels, and nanoparticles may be derived from cellulose's extreme flexibility. Among them, all are better for the environment and recyclable than conventional materials. Furthermore easily changed to satisfy various medication delivery requirements is cellulose. This allows one to create efficient, environmentally friendly, and functionally sound systems devoid of negative effects. For instance, cellulose products like carboxymethyl cellulose (CMC) and hydroxypropyl cellulose (HPC) can be changed to make drugs more biocompatible, dissolve better, and release drugs more slowly. Because of this, cellulose-based medicine capsules are not only good for the environment, but they can also be used in a lot of different medicinal situations.

B. Comparison with synthetic materials

Compared to man-made materials, cellulose-based drug carriers are more environmentally friendly, break down naturally, and work well with living things. Because they can be released slowly, synthetic polymers like polyethylene glycol (PEG), polylactic acid (PLA), and poly(lactic-co-glycolic acid) (PLGA) are often used in drug delivery systems. However, these materials are often made with resources that come from oil, and it could take years or even hundreds of years for them to break down in the environment. Instead, cellulose is recyclable and a naturally formed material, which makes it a better choice for the earth. One of the best things about cellulose-based carriers is that they can break down into harmless parts, which keeps dangerous materials from building up in the

environment. Synthetic polymers, on the other hand, may break down into microplastics or possibly dangerous by-products that stay in the environment and add to waste.

C. Life-cycle analysis and biodegradability

Based on their life-cycle analysis (LCA), cellulose-based pharmaceutical carriers seem to be more sustainable and ecologically benign than produced solutions. From the time it is manufactured until it is thrown away, the life cycle assessment (LCA) examines how an object influences the surroundings. It achieves this by considering issues such resource utilisation, energy use, pollution, and waste generation. Ecologically, cellulose-based carriers perform well as they come from green resources and break down organically, therefore reducing their overall effect on the surroundings. Cellulose is produced with a lot less energy than synthetic polymers, which are sometimes produced using hazardous chemicals and techniques consuming a lot of energy. Also, cellulose is easy to find and can be made from farming waste, which means that less land needs to be used intensively and less nonrenewable resources are needed. This is especially important now that the need for eco-friendly products is growing around the world. Synthetic materials, on the other hand, like PLA and PLGA, come from fossil fuels and need a lot of energy to be made, which makes their carbon footprints bigger.

RESULT AND DISCUSSION

Drug transport methods that use cellulose-based drug capsules have shown promise in making them last longer and work better. Different types of cellulose, like carboxymethyl cellulose (CMC) and hydroxypropyl cellulose (HPC), have been used successfully to hold different medicines and make sure they are released slowly and steadily. Furthermore, cellulose-based nanoparticles have shown to be better at carrying drugs, being stable, and being compatible with living things

Table 2: Drug Release Profile of Cellulose-Based Drug Carriers

Time (hrs)	CMC (%)	HPC (%)	CNC (%)
0.5	10.2	8.5	9.8
1	18.5	16.3	17
2	35	32.8	33.5
4	55.3	51.2	53

The drug release characteristics of cellulose-based drug carriers (CMC, HPC, and CNC) over time is shown in Table 2. All three cellulose products show a slow rise in drug release. In the first half hour, CMC released 10.2% of the drug, HPC released 8.5%, and CNC released 9.8%. This early release phase shows that cellulose-based carriers release drugs more slowly at first, which is good for controlled release formulas. For performance study, Figure 3 shows how the shares of CMC, HPC, and CNC have changed over time

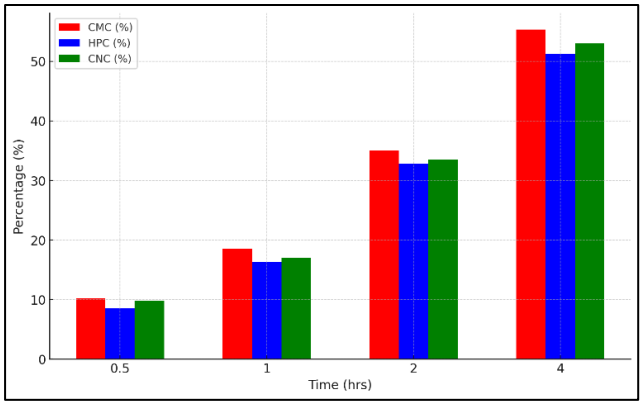

Figure 3: Comparison of CMC, HPC, and CNC Percentages Over Time

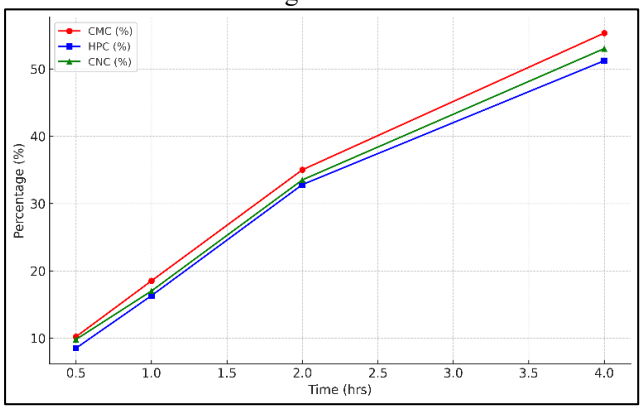

Figure 4: Trend of CMC, HPC, and CNC Percentages Over Time

This shows that these carriers are good at keeping drug release under control over time. Between two and four hours, when CMC released 55.3%, HPC released 51.2%, and CNC released 53%, there was the biggest rise in drug release. This shows that cellulose products can release drugs effectively and continuously, which makes them perfect for long-lasting healing benefits. The release patterns of CMC, HPC, and CNC are mostly the same, with only a few small differences. This shows that they could be used for controlled drug delivery

Table 3: Drug Encapsulation Efficiency of Cellulose-Based Carriers

Drug Type	CMC (%)	HPC (%)	CNC (%)
Anticancer	85.4	87.3	89.1
Antibiotic	82.1	80.5	84.2
Protein Drug	78.3	76.8	80
Peptide Drug	84.6	83.2	86.5

Table 3 displays how well different types of cellulose-based carriers (CMC, HPC, and CNC) encapsulate different types of drugs, such as antiviral, antibiotic, protein, and peptide drugs. Based on the data, all three types of cellulose

showed high packaging efficiency for all three types of drugs, with CNC usually showing the best efficiency. CNC had the best packaging rate for anticancer drugs, at 89.1%. HPC came in second, at 87.3%, and CMC came in third, at 85.4%.

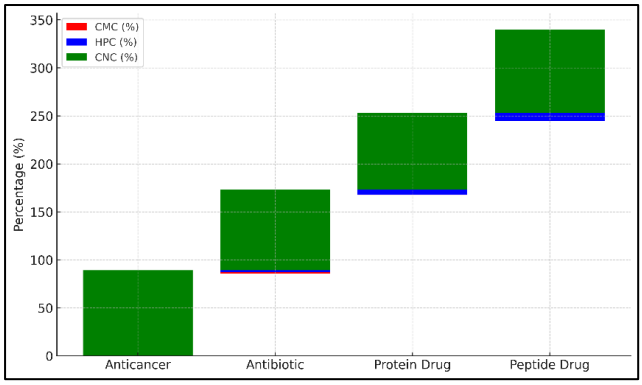

Figure 5: Accumulated Percentage of CMC, HPC, and CNC for Different Drug Types

This shows that CNC might be better at encasing drugs with bigger or more complicated structures. When it came to antibiotics, CMC worked 82.1% of the time, HPC 80.5% of the time, and CNC 84.2% of the time. Even though CNC worked the best, there weren't many changes between the three types of cellulose, which means that all of them can be used to give antibiotics. When it came to protein drugs, CNC had an encapsulation efficiency of 80%, while CMC and HPC had encapsulation efficiencies of 78.3% and 76.8%, respectively.

CONCLUSION

Cellulose-based drug capsules are an environmentally friendly and useful option to manufactured drug transport methods. Because it comes from green sources, cellulose is good for the earth in many ways, such as being biodegradable and not very harmful. Because cellulose can be changed into different forms, such as carboxymethyl cellulose (CMC), hydroxypropyl cellulose (HPC), and cellulose nanocrystals (CNC), it can be used to make drug delivery systems that are more stable, release drugs more slowly, and hold more drugs. These carriers can be modified to deliver medications to specific organs or tissues under regulated and long-lasting effect. This decreases adverse effects and enhances the outcomes of treatment. Researchers have discovered that carriers based on cellulose perform very well for several routes of drug delivery, including the mouth, an injection, or the skin. Controlled-release preparations made from cellulose can help to make medications that don't breakdown well more accessible when given orally. People don't have to get injections as regularly since injectable forms—such as cellulose-based hydrogels and nanoparticles—release medications slowly over time. By releasing medications only where they are required and facilitating skin absorption, topical drug delivery systems using cellulose-based carriers can help treat skin conditions

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