



Plant-Based Excipients in Modern Pharmaceutical Formulations: Recent Advances, Regulatory Challenges, and Future Perspectives

Ms. Sayali R. Raut¹, Mr. Krushna Changdev Shinde^{2*}, Ms. Sneha Sachin Throat³,

¹Assistant Professor, Department of Pharmacology, SMBT College of Pharmacy, Nandi Hills Tal Igatpuri Dist Nashik 422403. Sayaliraut2019@gmail.com

²Student, SMBT College of Pharmacy, Nandi Hills Tal Igatpuri Dist Nashik 422403. krushna6545@gmail.com

³Student, SMBT College of Pharmacy, Nandi Hills Tal Igatpuri Dist Nashik 422403. thoratsneha46@gmail.com

*Corresponding author: krushna6545@gmail.com, Sayaliraut2019@gmail.com

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ARTICLE HISTORY Received: 10-09-2026 Accepted: 20-09-2026 Published: 02-10-2026 CITATION *Shinde, K. C., Throat, S.S., (2026) Plant-Based Excipients in Modern Pharmaceutical Formulations: Recent Advances, Regulatory Challenges, and Future Perspectives, Journal of Novel Pharmaceutical Discoveries (JNPD). 1(3), 01-13.	Excipients are essential components of pharmaceutical formulations that improve drug stability, bioavailability, manufacturability, and patient acceptability. Traditionally, synthetic and semi-synthetic excipients have been widely used; however, growing concerns about toxicity, environmental sustainability, and patient safety have spurred interest in plant-derived excipients. Plant-based excipients obtained from natural sources such as gums, mucilages, starches, cellulose derivatives, and other phytopolymers possess excellent biodegradability, biocompatibility, low toxicity, and multifunctional properties. Recent advancements in pharmaceutical technology have expanded the use of plant-based excipients in both conventional dosage forms and novel drug delivery systems, including nanoparticles, microspheres, hydrogels, transdermal systems, and 3D-printed medicines. Natural polymers such as alginate, pectin, chitosan, starch, and cellulose derivatives have demonstrated significant potential in controlled release, targeted delivery, and improved therapeutic performance. Despite their advantages, challenges related to standardization, batch-to-batch variation, purity, stability, and regulatory acceptance limit their widespread industrial application. Advanced extraction methods, characterization techniques, and regulatory harmonization are required to overcome these limitations. This review discusses the classification, recent advances, pharmaceutical applications, regulatory challenges, and future perspectives of plant-based excipients in modern pharmaceutical formulations. Keywords: Plant-based excipients; Natural polymers; Pharmaceutical formulation; Drug delivery systems; Green pharmacy; Controlled release; Nanotechnology.

1. Introduction

Excipients for medicines are substances used in drug formulation to enhance the physical and chemical

characteristics, stability, manufacturability, and efficacy of the active components in medicines. Although

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excipients lack pharmacological activity, they play an important role in influencing drug release, availability, and the quality of pharmaceutical products. [1] Synthetic and semi-synthetic excipients have been used extensively for years in drug products due to their consistent quality and stability. But today, due to issues of toxicity, hypersensitivity, ecological concerns, and non-renewability of source materials, research is being conducted on finding better alternatives. [2] Plant-based excipients are naturally derived pharmaceutical materials obtained from various plant sources such as gums, mucilages, starches, cellulose derivatives, pectins, and other natural polymers. These excipients possess several advantages, including biodegradability, biocompatibility, low toxicity, availability, and cost-effectiveness, making them attractive alternatives to conventional excipients. [3] Natural polymers derived from plants have shown various applications in the formulation of medicines. These can be used as binding agents, disintegrating agents, suspending agents, coating agents, thickening agents, and matrix-forming controlled-release agents. As an example, starch derivatives are often used as binding and disintegration agents in tablets, and cellulose derivatives like HPMC are commonly employed in sustained-release drug delivery systems. [4] Modern developments in drug delivery technology have extended the usage of plant excipients to include nontraditional dosage forms. These natural polymers have been explored in new drug delivery systems, such as nanoparticles, microspheres, hydrogels, transdermal systems, and even three-

dimensional printed drugs. Their ability to influence the release of a drug and its effectiveness has made their use more significant in drug development nowadays. [5] The rising need for environmentally friendly pharmaceutical practice has increased the acceptance of the term “green pharmacy” as far as the use of renewable and biodegradable sources is concerned. Excipients of plant origin are helpful for the environmentally friendly development of pharmaceutical drugs. [6] However, despite having some benefits, plant-based excipients for pharmaceutical use are associated with certain challenges, that are associated with their chemical variability, seasonality, method of extraction, contamination risk, lack of standardization, and difficulty in obtaining regulatory approval. [7] Consequently, plant-derived excipients become a prospective subject of pharmaceutical investigations, since they offer possibilities for creating safer and more eco-friendly drug delivery systems. The present review presents the current state of plant excipients as concerns their classification, recent developments, applications, regulations, and prospects.

Classification of Plant-Based Excipients

Excipients derived from plants are grouped based on the natural source of the excipient, chemical structure, and their pharmaceutical purpose. The excipients are mostly sourced from plant gums, mucilage, starch, cellulose derivatives, marine and plant polysaccharides, among other natural polymers. [8]

1 Classification Based on Natural Source

Source Category	Examples	Chemical Nature	Pharmaceutical Applications
Plant Gums	Acacia gum, Guar gum, Xanthan gum, Karaya gum	Polysaccharides	Binder, suspending agent, thickener, stabilizer
Plant Mucilages	Isabgol (Psyllium), Aloe vera mucilage, Okra mucilage	Hydrophilic polysaccharides	Disintegrant, binder, controlled-release agent

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Starches	Maize starch, Potato starch, Rice starch	Natural carbohydrate polymer	Tablet binder, diluent, disintegrant
Cellulose Derivatives	HPMC, CMC, Ethyl cellulose	Modified polysaccharides	Film coating, matrix former, sustained release
Pectins	Citrus pectin, Apple pectin	Galacturonic acid polymer	Gel forming agent, colon drug delivery
Plant Proteins	Soy protein, Zein	Natural proteins	Drug carrier, film-forming agent
Natural Resins	Guar resin, Shellac	Complex polymers	Coating and release modification

2 Classification According to Pharmaceutical Uses [9]

A. Binders

Binders enhance the strength of tablets by creating bonds among the powder particles.

List of some binders:

- Acacia gum
- Starch paste
- Pectin
- Guar gum

Uses:

- Granulation of tablets
- Strength of tablets

B. Disintegrating Agents

The disintegrants cause breakdown of the tablet after it is swallowed, thereby ensuring drug dissolution.

Examples include:

- Pregelatinized starch
- Cellulose derivatives of plants
- Mucilage of Isabgol

Applications:

Immediate release tablets [10]

C. Suspending Agents

The natural gums ensure increased viscosity and even suspension of insoluble particles of drugs in liquids.

Examples:

- Acacia
- Xanthan gum
- Tragacanth gum

Applications:

- Pharmaceutical suspensions
- Syrups [11]

D. Controlled Release Polymers

These polymers derived from plant sources control the delivery of drugs for extended periods.

Examples:

- HPMC
- Alginate
- Pectin
- Chitosan

Applications:

- Controlled release tablets
- Microspheres
- Nanocarriers [12]

E. Film-Coating Agents

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Plant-sourced polymers provide a protective film-coating along with enhanced stability.

Examples:

- Cellulose derivatives
- Starch derivatives

Applications:

- Tablet coating
- Taste masking [13]

3 Importance of Plant-Based Excipients

Plant-based excipients offer several advantages:

- Renewable and sustainable source
- Biocompatible and biodegradable
- Low toxicity
- Cost-effective
- Wide functional applications
- Suitable for novel drug delivery systems

However, their natural origin may cause variability in composition and requires proper standardization before pharmaceutical use. [14]

Recent Advancements in Plant Origin Excipients

The recent advancements in pharmaceutical science have increased the application of plant origin excipients beyond their conventional use as formulation aids to become a sophisticated system for drug delivery. Biodegradable, biocompatible and modifiable properties of the natural polymer have led to their increased application in novel pharmaceutical systems such as nanoparticles, hydrogels, microspheres and personalized medicine. [15]

1 Applications based on Nanotechnology

Nanotechnology provides new possibilities for the application of natural excipients derived from plants in drug delivery. Natural polymers such as alginate, pectin, starch, cellulose derivatives, and chitosan are used in nanoparticle and nanogel formation.

The use of these polymers results in the following advantages:

1. Increased drug stability
2. Improved solubility of drugs that are insoluble in water
3. Controllable drug release
4. Specific targeting

Alginate-based nanoparticles can be used for oral administration of proteins and anticancer drugs owing to their high biocompatibility and protective features. [16]

2 Controlled and Sustained Drug Delivery Systems

Plant polymers are widely used as matrix-forming materials for sustained release of drugs. Due to their swelling capacity, ability to form gels, and biodegradability, plant polymers provide prolonged delivery of pharmaceutical active ingredients.

Polymers include:

- hydroxypropyl methylcellulose (HPMC),
- pectin,
- guar gum,
- xanthan gum,
- alginate.

They prolong the release of therapeutically effective drug concentrations. [17]

4.3 Natural Excipients of Plant Origin in Nanocarriers and Targeted Delivery

Natural polymers play an important role in developing novel carriers including:

- Nanoparticles
- Lipid-polymer nanoparticles
- Microspheres
- Nanogels

The benefits associated with these carriers include:

- Low toxicity
- Increased bioavailability

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- Drug protection
- Therapeutic efficacy

Pectin and alginate-based drug delivery systems have proven to be effective in delivering drugs in a targeted manner, particularly in the GIT and colon. [18]

4 Applications of 3D Printed Pharmaceuticals

3D printing is a recent technology in personalized medicine. Natural polymers derived from plants have been suggested as potential printing materials for pharmaceuticals due to their adaptability, non-toxicity, and biodegradability.

Examples:

- Cellulose derivatives
- Starch-based polymers
- Natural hydrogels

Applications:

- Specific dosage form for patients
- Drug release systems
- Pediatric formulations [19]

5 Green Pharmaceutical Production

Summary Table: Recent Advances

Advancement	Plant-Based Excipients Used	Application
Nanoparticles	Alginate, Chitosan, Pectin	Targeted drug delivery
Controlled release	HPMC, Guar gum, Xanthan gum	Sustained drug release
Hydrogels	Alginate, Cellulose	Tissue/drug delivery systems
3D Printing	Starch, Cellulose derivatives	Personalized medicine
Green pharmacy	Natural polymers	Sustainable formulation
Smart delivery	Pectin, Alginate	Stimuli-responsive systems

Applications of plant-based excipients in pharmaceutical formulations

The use of plant-based excipients in the preparation of pharmaceutical formulations is gaining importance

The term green or sustainable pharmacy is related to the reduction of environmental effects associated with the development of drugs. The use of plant excipients is aligned with this philosophy since they are:

- From renewable sources
- Biodegradable
- Environmentally friendly
- Reduced dependence on petro-chemicals

This can be achieved by the use of natural polymers. [20]

6 Intelligent and Stimuli-Sensitive Plant-Derived Excipients

Modern studies are aimed at the design of intelligent excipients sensitive to biological stimuli, including:

- pH variation
- Temperature change
- Enzymatic environment

Specific examples:

- Pectin derivatives for colon-specific drug delivery
- Alginate hydrogel systems
- Cellulose-based sensitive materials

Such formulations increase the efficacy of the drug action. [21]

because of the many functions that these excipients possess. These are used not only for conventional dosage forms but also for more complex drug delivery systems. [22]

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1 Application in Tablet Formulations

Tablets are the most commonly used pharmaceutical dosage forms where plant-based excipients play

multiple roles such as binders, diluents, disintegrants, and release modifiers.

Examples and Functions

Plant-Based Excipient	Role in Tablet Formulation
Starch	Binder and disintegrant
Acacia gum	Binding agent
Guar gum	Sustained-release polymer
Plant cellulose derivatives (HPMC, CMC)	Matrix-forming agent
Isabgol mucilage	Disintegrant and release modifier

Natural polymers improve tablet hardness, drug release, and dissolution characteristics. [23]

2 Application in Capsules

Plant-based ingredients can be incorporated in capsule formulation as substitutes for animal-based gelatin.

Some examples are:

- Hydroxypropyl methylcellulose (HPMC)
- Cellulose derivatives
- Starch-based capsule materials

Benefits:

- Suitable for vegetarians and vegans
- Less risk of contamination
- Good patient compliance

The use of plant-based capsules is on the rise in the pharmaceutical industry. [24]

3 Application in Liquid Formulations

Natural gums and mucilages are extensively used in liquid preparations as:

- Suspending agent
- Stabilizer
- Viscosity modifier

Examples:

- Acacia gum
- Xanthan gum
- Tragacanth gum
- Aloe vera mucilage

These ensure uniform suspension of drugs in suspensions and syrups. [25]

4 Applications in Controlled Drug Delivery System

Plant-based polymers have been widely studied for sustained and controlled release drug delivery owing to their swellability and gel-forming nature.

Popularly used polymers:

- HPMC
- Alginate
- Pectin
- Guar Gum

Applications:

- Matrix tablet
- Microsphere
- Implants
- Hydrogels

Such formulations offer sustained drug release and decreased dose frequency. [26]

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5 Applications in Nano-Based Drug Delivery

Natural polymers are useful in the preparation of:

- Nanoparticles
- Nanogels
- Nanoemulsions
- Polymeric vehicles

Advantages:

- Increased drug solubility
- Increased bioavailability
- Decreased toxicity
- Targeted drug delivery

Examples:

- Alginate nanoparticles for protein delivery
- Chitosan nanoparticles for gene and drug delivery
- Pectin nanoparticles for colon-targeted drug delivery [27]

6 Application in Topical and Transdermal Formulations

Plant-based excipients are used in:

- Creams
- Gels
- Ointments
- Transdermal patches

Examples:

Excipient	Application
Aloe vera gel	Moisturizing and gel base
Chitosan	Film-forming agent
Cellulose derivatives	Viscosity enhancer

They improve spreadability, stability, and skin compatibility. [28]

Used for:

- Sustained drug delivery

7 Application in Novel Drug Delivery Systems

Modern research focuses on plant-derived excipients for advanced systems:

Mucoadhesive systems

Used for:

- Buccal and nasal drug delivery

Hydrogels

Used for:

- Wound healing
- Controlled drug release

Colon-targeted systems

Used for:

- Site-specific delivery of drugs

Natural polymers such as pectin and alginate are especially useful due to their biodegradability and biological compatibility. [29]

Microspheres

Table: Summary of Pharmaceutical Applications

Dosage Form/System	Plant-Based Excipients	Main Function
Tablets	Starch, HPMC, Guar gum	Binder, disintegrant, sustained release

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Capsules	HPMC, cellulose	Capsule shell material
Suspensions	Acacia, Xanthan gum	Stabilizer, suspending agent
Hydrogels	Alginate, Pectin	Controlled delivery
Nanoparticles	Chitosan, Alginate	Targeted delivery
Topical products	Aloe vera, cellulose	Gel base, thickener
3D printing	Starch, cellulose	Personalized medicines

Regulatory Problems Associated with Plant-Based Excipients

Despite the enormous application of plant-based excipients in the production of medicines, their practical implementation is restricted by several problems related to regulations and quality. Natural excipients are different from synthetic ones as they consist of a wide range of chemical compounds, which depend on plant type, geographical location, growing conditions, harvesting period, and processing method. Thus, appropriate standardization and regulation are crucial for pharmaceutical applications of natural excipients. [30]

1 Lack of Standardization and Quality Assessment

The main problem related to plant-based excipients is that they do not ensure consistent quality. Natural substances consist of numerous chemical substances; therefore, their composition may vary from batch to batch.

The following factors affect the quality of plant-based substances:

- Variety and type of plants
- Climate and soil conditions
- Extraction and purification processes
- Storage conditions
- Processing methods

Modern analytical methods like:

- FTIR spectroscopy
- HPLC analysis

- NMR spectroscopy
 - Chromatographic fingerprinting
- are needed for identification and quality assessment of natural excipients. [31]

2 Variability Between Batches

Synthetic excipients normally have a specific chemical structure, while plant-based excipients usually exhibit variability in:

- Molecular weight
- Viscosity
- Water content
- Properties of the substance
- Chemical composition

It will affect:

- Release profile of the drug
- Stability
- Bioavailability
- Production process

Thus, setting limits of acceptability of the product will be needed before its application. [32]

3 Approval Issues

Safety and quality evaluations are performed at the highest level by regulatory authorities before approval of the novel excipient.

Regulatory agencies are:

- US Food and Drug Administration (FDA)
- European Medicines Agency (EMA)

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- Central Drugs Standard Control Organization (CDSCO), India
- International Council for Harmonisation (ICH)

The following evaluation is performed:

- Toxicity testing
- Stability testing
- Microbial contamination evaluation
- Compatibility with APIs [33]

4 Issues of Safety and Contamination

Plant-based products may contain undesirable components such as:

- Heavy metals
- Microbes
- Pesticides
- Endotoxins
- Allergens

Proper purification and quality testing are necessary to ensure the safety of the pharmaceutical product.

Examples of safety evaluation:

- Microbial limit tests
- Heavy metal testing
- Toxicological testing [34]

5 Lack of Regulation Guidelines for Novel Plant Excipients

Table: Major Regulatory Challenges and Solutions

Challenge	Impact	Possible Solution
Batch variability	Inconsistent formulation performance	Standardization methods
Lack of characterization	Quality issues	Advanced analytical techniques
Contamination risk	Safety concerns	Purification and testing
Limited guidelines	Delayed approval	Regulatory harmonization

Traditional plant products have been used in medicines, but novel plant excipients do not always have regulatory guidelines.

The problems faced in this regard are:

- Absence of a monograph
- Lack of information on safety
- Difficulties in specifying the guidelines
- No international coordination

Creation of standards on a global level is needed to promote innovation. [35]

6 Stability and Storage Issues

Natural polymers may be influenced by:

- Temperature
- Humidity
- Oxidation
- Microbial activity

This may change their characteristics while they are stored.

Solutions:

- Proper packaging
- Storage under controlled conditions
- Modification through chemical reaction
- Stabilization process [36]

Stability issues	Reduced shelf life	Improved storage methods
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Future Perspectives of Plant-Based Excipients

The future of plant-based excipients in pharmaceutical science appears highly promising owing to the growing need for sustainable, safe, and multifunctional formulation ingredients. Biotechnology, nanotechnology, and pharmaceutical engineering are anticipated to help solve problems connected with variability, standardization, and regulation of plant-based excipients. Plant-based excipients will likely find use as important components in drug delivery systems of the future. [37]

1 Development of Smart and Functional Excipients

In the future, research will be dedicated to creating smart excipients, capable of responding to biological environment factors like:

- Changes in pH
- Variation in temperature
- Enzyme activity
- Disease-specific microenvironment

Examples:

- Pectin-based polymers for colonic targeted drug delivery
- Alginate-based hydrogels for controlled release
- Cellulose-based drug delivery systems

Intelligent excipients will enhance drug delivery specificity and effectiveness. [38]

2 Nanotechnology Integration

Integration of plant-based polymers with nanotechnology is a future direction that is worth considering.

Possible uses include:

- Polymeric nanoparticles
- Nano-hydrogels

- Nanofibers
- Targeted drug delivery systems

Benefits:

- Improved solubility of drugs
- Increased bioavailability
- Minimized side effects
- Regulated drug release

Natural polymers like alginate, chitosan, pectin, and cellulose will be important for future developments in nanomedicine. [39]

3 AI-Based Excipient Selection

Machine learning approaches based on artificial intelligence might be used for improvement in excipient selection and formulation design.

AI may assist in:

- Drug-excipient compatibility prediction
- Optimization of formulation
- Formulation development time reduction
- Personalized medicine creation

AI-based formulation development may speed up research in new excipients of natural origin. [40]

4 Personalized Medicine and 3D Printing

The personalized medicine approach needs personalized dosage forms, which need to be designed based on patients' requirements. The plant-based excipients are applicable in 3D printing technology since they have:

- Biocompatibility
- Biodegradability
- Processing flexibility

The potential future applications include:

- Customized tablets
- Dosage forms for pediatric patients
- Customized drug-release profiles [41]

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5 Eco-Friendly Pharmaceutical Manufacturing

Sustainability of the environment is a growing concern in pharmaceutical industries. The plant-based excipients contribute to sustainable pharmaceutical development since they:

- Use renewable sources
- Contribute to minimal environmental waste
- Contribute to reduced dependence on synthetic chemicals
- Provide biodegradable formulations

Future pharmaceutical manufacturing will involve the use of green natural materials. [42]

6 Chemical Modification of Natural Polymers

Chemical modification of plant-based polymers helps to improve their:

- Solubility
- Stability
- Mechanical property
- Drug release

Examples include:

- Modified starch
- Crosslinked alginate
- Carboxymethyl cellulose

Such modification could increase the applicability in drug delivery systems. [43]

Future Research Opportunities

Future Area	Potential Application
Smart excipients	Disease-specific drug delivery
Nanotechnology	Targeted therapy
AI-based design	Faster formulation development
3D printing	Personalized medicines
Green pharmacy	Sustainable drug products
Polymer modification	Improved functionality

Conclusion

Pharmaceuticals made from plants have become useful materials for medicines because of their natural source, biodegradability, safety, and multi-functionality. They have shown various applications not only in traditional dosage forms but also in nanoparticles, hydrogels, and personalized medicines. Despite several advantages, the problem of standardization, regulatory issues, stability,

and quality control remains important. Modern analytical technologies, biotechnology, nanotechnology, and artificial intelligence approaches could be used as an effective way to overcome the above-mentioned problems. In the future, the development of new drug formulations is likely to be accompanied by a growing use of plant-based excipients as sustainable and innovative materials compared to traditional materials.

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