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NATURAL EXCIPIENTS AS ALTERNATIVES TO SYNTHETIC EXCIPIENTS: A COMPREHENSIVE REVIEW

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ABSTRACT:

Excipients are non-active pharmaceutical components that play an essential role in medication formulation by enhancing the stability, bioavailability, and acceptability of the active pharmaceutical ingredient for patients. Historically, synthetic excipients have been the predominant choice in formulating numerous pharmaceutical products due to their reliability in quality and performance. Nonetheless, the increasing problems of toxicity, environmental issues, and the difficulty in regulating synthetic excipients, along with the elevated production costs associated with them, have prompted researchers to direct their focus towards utilizing natural excipients as alternatives to synthetic ones. This article reviews the significance of natural excipients in contemporary pharmaceutical formulations. Attention is focused on their diverse functional characteristics including binder, disintegrant, emulsifier, and stabilizer. Moreover, developments in their extraction, characterization, and modification are also discussed. Additionally, issues concerning variability, microbial contamination, and standardization are thoroughly examined. In summary, due to the increasing demand for environmentally friendly and patient-centric formulations, natural excipients are viewed as alternatives to synthetic counterparts.

KEYWORDS: Natural additives, Synthetic additives, Compatibility Drug administration, drug formulations, Degradable polymers

2. INTRODUCTION

Excipients are pharmaceutical formulation additives that, when mixed with active pharmaceutical ingredients, produce a final pharmaceutical product. Excipients may not participate directly in pharmaceutical action, but they perform numerous roles that guarantee a pharmaceutical product's effectiveness, stability, and suitability for patient use.[1] Excipients, while inactive, serve as additives to pharmaceutical vehicles, diluents, binders, disintegrants, lubricants, preservatives, emulsifiers, and coatings, based on the specific type of pharmaceutical formulation. For example, in tablet formulation, a binder is employed to enhance tablet durability, while a disintegrant is utilized to decompose a tablet in the gastrointestinal system for improved drug release. Likewise, in a liquid formulation, excipients like emulsifiers and suspending agents are utilized to guarantee even distribution of a medication.[2]

Excipients play a crucial role not just in the formulation of drugs but also in their pharmacokinetics and pharmacodynamics. Excipients may enhance the solubility of drugs with low solubility, regulate the

10.48047/jocaaa.2024.32.01.93

release of the drug in modified release formulations, and increase patient compliance by masking the drug's taste or smell. Excipients play a vital role in the targeted delivery of drugs within the development of sophisticated drug delivery systems like nanoparticles, liposomes, and self-emulsifying drug delivery systems. Therefore, the function of excipients in the formulation development process is one of the most crucial elements.[3]

In drug development, excipients hold the same significance as APIs, as they can greatly impact the quality, safety, and effectiveness of a pharmaceutical product. Thus, it is essential that a pharmaceutical product is created by merging excipients suitable for producing an effective product. Excipients can greatly affect pharmaceutical production processes such as granulation, compression, and coating.[4] Excipients can differ in compatibility, which can lead to setbacks in the development of pharmaceutical products. Regulatory bodies focus heavily on the safety and quality of excipients, encompassing characterization, toxicity, and pharmacopoeial specifications. With the ongoing advancements in pharmaceutical technologies, there is a growing need for excipients to be more functional, resulting in the creation of new and innovative excipients.[5]

Excipients can be categorized according to their source or purpose. When categorized by origin, they fall into three classifications: natural, semi-synthetic, and synthetic excipients. Natural excipients are obtained from plant sources such as gums, mucilage, or starch; animal sources like gelatin; or mineral sources such as talc or kaolin. Semi-synthetic excipients originate from naturally found substances such as cellulose, which undergo chemical modifications to improve their performance relative to their natural equivalents.[6] Chemically synthesized excipients are used to give quality and particular functional properties to the final dosage form, such as polyvinylpyrrolidone or polyethylene glycol. Excipients can be categorized into various types based on their function, such as diluents, binders, disintegrants, lubricants, glidants, emulsifiers, stabilizers, preservatives, and coating substances.

Despite the extensive use of synthetic excipients, concerns regarding safety and environmental impacts linked to synthetic excipients have been increasing. Certain synthetic excipients may lead to hypersensitivity, toxicity, and negative health impacts.[7] These artificial excipients may lead to negative health impacts, particularly in vulnerable groups like children and elderly individuals. Additionally, synthetic excipients may lead to environmental contamination as their manufacturing entails intricate chemical processes that can generate harmful by-products. Challenges related to regulations and the costs of synthetic excipients further hinder their acceptance. These challenges have prompted researchers and formulation specialists to explore safer alternative excipients.[8]

In recent years, there has been an increasing interest in utilizing natural excipients as possible alternatives to synthetic excipients. Natural excipients are regarded as safe, biodegradable, biocompatible, and eco-friendly. They are also easily accessible, affordable, and obtained from renewable sources. Plant-derived polymers, such as gums like guar gum and acacia, along with mucilages like psyllium husk and starch, have demonstrated potential as binders, disintegrants, and release modifiers. Moreover, advancements in the extraction, purification, and modification of excipients have enhanced the performance and consistency of natural excipients, making them similar to synthetic excipients. The increasing consumer demand for ‘green’ and ‘clean label’ pharmaceuticals has spurred interest in utilizing natural excipients.[9]

Nonetheless, utilizing these excipients presents its own set of challenges. The differences in the characteristics of these excipients caused by variations in geographic regions, climate, and harvesting conditions can lead to issues regarding their consistency. Issues such as microbial limits, shelf life, and standardization must be addressed to guarantee the effective use of these excipients in

10.48047/jocaaa.2024.32.01.93

pharmaceutical dosage forms. Therefore, studies must be conducted to address these challenges in the effective use of these excipients.[10]

The primary goal of this review is to provide a comprehensive summary of natural excipients as alternatives to synthetic excipients in pharmaceutical formulations. The examination aims to address the sources, characteristics, functions, benefits, and drawbacks of natural excipients, along with recent advancements in their formulation and use. The review aims to emphasize the challenges related to the use of natural excipients and the ways they can be tackled. This review aims to highlight the significance of natural excipients in advancing environmentally friendly and patient-oriented drug development by identifying trends and opportunities.[11]

3. OVERVIEW OF SYNTHETIC EXCIPIENTS

3.1 Definition and Examples of Synthetic Excipients

Chemically manufactured synthetic excipients serve as additives in medications to enhance the stability, delivery, and effectiveness of drugs.

Examples:

• Polyethylene glycol (PEG): Functions as a solvent, plasticizer, and foundation in ointments and tablets.

• Polyvinylpyrrolidone (PVP): Commonly serves as a binder and solubilizing agent.

• Hydroxypropyl methylcellulose (HPMC): A semi-synthetic polymer employed in controlled release formulations and as a film coating.

• Sodium lauryl sulfate (SLS): A detergent utilized to improve the dissolution of medications.[12]

3.2 Advantages of Synthetic Excipients

• Uniformity: The uniformity of synthetic excipients is a major benefit as they can be produced in a consistent manner.

• Availability: They can be easily procured in significant amounts due to the existence of effective manufacturing methods.

• Cost-efficiency: They may also be produced in substantial amounts due to adequate manufacturing processes.[13]

3.3 Constraints of Artificial Excipients

• Toxicity concerns: There is a chance that synthetic excipients could be cytotoxic or irritate tissues, particularly with extended use or at elevated concentrations.

• Environmental concerns: The production of these excipients could lead to the use of non-renewable resources, causing environmental contamination from the generation of harmful by-products.

• Regulatory challenges: Regulations are quite strict, potentially leading to increased development expenses because of comprehensive safety assessment processes.

• Hypersensitivity: Certain excipients, such as SLS or PEG, can lead to hypersensitivity in some individuals.[14]

10.48047/jocaaa.2024.32.01.93

4. NATURAL EXCIPIENTS: AN INTRODUCTION

4.1 Definition

Natural excipients are non-harmful and pharmacologically inactive materials obtained from natural sources like plants, animals, and minerals. These compounds are utilized in drug formulations to aid in the delivery of active pharmaceutical substances. In contrast to synthetic excipients, natural excipients undergo minimal processing and retain inherent properties. They are comparatively safer and more eco-friendly. Excipients sourced from natural origins have been thoroughly examined and have received significant attention due to their eco-friendly chemistry properties.[15]

4.2 Classification of Natural Excipients

Natural excipients can be broadly classified based on their origin into five major categories:

Figure No. 1 Classification of Natural Excipients as per the source

- ✓ **Plant-Based Excipients:** Botanical Excipients: Botanical excipients come from various plant components such as seeds, roots, and bark. Examples consist of gums such as acacia or guar gum, mucilages like psyllium, and starches such as corn or potato.
- ✓ **Animal-Derived Excipients**: Animal-derived excipients originate from animals, such as gelatin, which is sourced from collagen, or chitosan, which is obtained from crustacean shells.[16]
- ✓ **Excipients from Minerals:** Mineral-based excipients are naturally found inorganic substances such as talc or calcium carbonate. They serve as fillers, glidants, or stabilizers due to their inert nature and excellent physicochemical stability.
- ✓ **Marine Sources:** Excipients from marine origins come from seaweeds or different marine organisms. They are commonly utilized because of their effective gelling, thickening, or stabilizing characteristics.[17]

Alginates:

- ✓ Alginates come from brown seaweed. They serve as gelling agents, stabilizers, and controlled release polymers in pharmaceutical formulations due to their ability to form hydrogels when calcium ions are present.

10.48047/jocaaa.2024.32.01.93

Carrageenan:

- ✓ Carrageenan is obtained from red seaweed. Carrageenan serves as a thickening agent and emulsifier in pharmaceutical products. Carrageenan enhances the thickness of pharmaceutical suspensions.
- ✓ Microbial Sources: Microbial excipients originate from microorganisms via fermentation processes. Microbial excipients are recognized for their excellent purity, reliability, and adaptability.[18]

Xanthan Gum:

- ✓ Xanthan gum is derived from the bacterium Xanthomonas campestris. Xanthan gum serves as a thickening agent, suspending agent, and stabilizer in medications. Xanthan gum exhibits significant viscosity even when present in low amounts. Xanthan gum exhibits a wide range of stability in pH and temperature.
- ✓ Dextran:

Dextran is a polysaccharide obtained by bacteria of the *Leuconostoc* group. Dextran is used as a plasma volume expander and also as a binder and stabilizer[19]

4.3 General Properties of Natural Excipients

1. Natural things are biodegradable: This means that natural excipients can break down easily into things that will not harm us. So we do not have a lot of waste and pollution in the environment.

2. Natural excipients are biocompatible: This means that natural excipients are okay, for our bodies. They do not get in the way of the way our bodies work. So natural excipients are safe to use when we make medicine.[20]

3. Natural excipients are not toxic: It means that natural excipients will not hurt us. We can use excipients for a long time and they will still be safe.

4. Natural excipients are renewable: This means that we can get natural excipients from nature. We can grow plants and get more natural excipients from them. Natural excipients come from resources and we can always get more of them**.**[21]

5. FUNCTIONAL ROLES OF NATURAL EXCIPIENTS

In pharmaceutical formulations, natural excipients serve a variety of purposes. These include enhancing the delivery and stability of medications. Natural excipients are good substitutes for synthetic ones because of characteristics like swelling and viscosity.

1. Binders: Powder particles are held together by natural binders. They also contribute to a tablet's mechanical strength. Guar gum, acacia, and starch are among the materials used. These materials aid in the correct production of tablets and are cohesive.[22]

2. Disintegrants: These break down tablets into smaller pieces. This is done in order to swiftly release the medication. Materials like mucilage and starch are utilised. When these materials come into touch with water, they swell. As a result, the tablet disintegrates due to internal pressure.[23]

3. Diluents and fillers: These are used to make a medication bulkier. This is carried out when a medication's dosage is incredibly low. Lactose and starch are among the materials used. These compounds aid in giving a medication consistency.[24]

4. Lubricants: When compressing tablets, natural lubricants lessen the friction between the tablet and the die walls. This facilitates the manufacturing process. Some naturally occurring lubricants, such talc and stearic acid, are utilised to smoothly eject pills and keep them from adhering.[25]

10.48047/jocaaa.2024.32.01.93

5. Emulsifying Agents: By lowering the interfacial tension between two non-miscible liquids, natural emulsifying agents aid in the creation of stable emulsions. Gums such as tragacanth and acacia help create stable emulsions by covering the scattered liquid droplets with a protective layer.[26]

6. Suspending Agents: Liquid dosage forms of insoluble active drug compounds are prepared using natural suspending agents. The two agents utilised to stop the insoluble active medicinal ingredients from settling in liquid forms are xanthan and guar gums.[27]

7. Film-Forming Agents: Tablets and capsules are coated with natural film-forming agents. They aid in the controlled release of the active ingredients of drugs and offer protection. The two substances utilised to create thin, flexible films are cellulose and alginates.[28]

Functional Role Natural Excipients (Examples) Function in Formulation Mechanism/Property

Table No. 1: Functional Roles of Natural Excipients

Functional Role	Natural Excipients (Examples)	Function in Formulation	Mechanism/Property	Reference
Binders	Starch, Acacia, Guar gum	Provide cohesiveness to powders and form tablets with adequate strength	Form adhesive matrix during granulation	29
Disintegrants	Starch, Psyllium husk, Mucilage	Promote breakup of tablets after administration	Swelling and water absorption (wicking action)	30
Fillers / Diluents	Lactose, Cellulose, Starch	Increase bulk and improve compressibility	Provide volume and uniformity	31
Lubricants	Stearic acid (plant-based), Waxes	Reduce friction during tablet compression	Form a thin layer to prevent sticking	32
Emulsifying Agents	Acacia, Lecithin	Stabilize oil-water mixtures	Reduce interfacial tension and form protective film	33
Suspending Agents	Xanthan gum, Tragacanth, Alginates	Maintain uniform dispersion of particles in liquid	Increase viscosity and prevent sedimentation	33
Film-Forming Agents	Chitosan, Starch, Cellulose derivatives	Provide coating to tablets/capsules	Form thin, protective and biodegradable films	33

Table no. 2 . COMPARATIVE ANALYSIS: NATURAL VS SYNTHETIC EXCIPIENTS

Parameter	Natural Excipients	Synthetic Excipients	Reference
Safety Profile	Long-term use and sensitive populations can benefit from this generally recognised as safe (GRAS) medication, which has	Well-characterized and safety-tested, however some (like SLS and PEG) may be poisonous, irritating, or	34

10.48047/jocaaa.2024.32.01.93

	low toxicity and improved patient tolerance. However, if improperly treated, microbial contamination and unpredictability may present small dangers..	trigger hypersensitivity reactions, particularly when used over extended periods of time or at greater concentrations..	
Biodegradability	Extremely eco-friendly and biodegradable; readily decomposes into non-toxic byproducts, lessening the impact on the environment.	Chemical synthesis and disposal can contribute to environmental contamination because they are frequently non-biodegradable or slowly degradable.	35
Cost Comparison	Natural availability and renewable resources make them generally affordable; nevertheless, processing, purification, and standardisation can raise expenses.	Large-scale production is cost-effective because of established industrial procedures; controlled manufacturing keeps costs steady.	36
Functional Efficiency	May show multifunctional properties (e.g., starch as binder and disintegrant), but performance can vary depending on source, season, and processing conditions.	Designed expressly for specialised functions in formulations, it is incredibly efficient and performs consistently and predictably.	37
Stability Issues	Prone to microbial contamination, moisture sensitivity, and batch-to-batch variability; may require preservatives and special storage conditions.	Demonstrate superior chemical and physical stability, a longer shelf life, and less environmental sensitivity.	38

7. REWARDS OF NATURAL EXCIPIENTS

1. Eco-Friendly and Sustainable: Natural excipients support the growth of green pharmacies because they are biodegradable and made from renewable resources.
2. Safe and Patient-Friendly: Natural excipients are safe for patients, particularly young and elderly patients, due to their low toxicity, excellent biocompatibility, and minimal adverse effects.
3. Versatile and Fit for Advanced Systems: Natural excipients are easily accessible and have the benefit of being multipurpose, which makes them appropriate for novel drug delivery methods like bioadhesive and controlled release.[39]

8. RESTRICTIONS OF NATURAL EXCIPIENTS

1. Microbiological and Stability Problems:
Natural excipients may carry the danger of microbial contamination and moisture sensitivity. For the product's shelf life, this can call for extra precautions.
2. Problems with Variability and Standardisation:
Inconsistencies in the source materials and processing conditions may pose problems in the standardization of natural excipients.
3. Regulatory and Processing Concerns:
Natural excipient manufacturing and processing may provide challenges due to their complexity and lack of standardised protocols.[40]

10.48047/jocaaa.2024.32.01.93

9. APPLICATIONS IN PHARMACEUTICAL DOSAGE FORMS

Because of their versatility, safety, and biocompatibility, natural excipients are utilised in a wide range of pharmaceutical dosage forms. Their significance is emphasised in improving patient acceptance, medication release, and dosage form efficiency.

9.1 TABLETS

In tablet formulations, natural excipients are used in critical areas, including **binders** and **disintegrants**.

• Binders, such as starch, acacia, and guar gum, give powder mixes cohesion, giving the tablets the proper hardness and strength. They inhibit tablet breakage during handling and transportation and aid in the creation of granules in wet granulation.
• When pills come into touch with gastrointestinal fluids, disintegrants including starch, mucilage, and psyllium help them dissolve quickly. Through hydration and swelling, they improve the availability and solubility of drugs. In addition, natural excipients may be used as fillers and lubricants, thus enhancing compressibility and manufacturability. They are non-toxic and biodegradable, thus suitable for long-term oral administration.[41]

9.2 Capsules

Natural excipients are frequently utilised in capsules, particularly in soft gel and hard capsules. • Due to its excellent film-forming and gelling qualities, gelatin—a naturally occurring polymer derived from collagen—is the most commonly utilised excipient in the production of capsules.• Other naturally derived excipients, including as pullulan and starch, are being employed in vegetarian capsules, which offer improved patient and cultural acceptability.

In addition to providing the necessary encapsulation and release properties, natural excipients are utilised in capsules as fillers, stabilisers, and release agents.[42]

9.3 Suspensions and Emulsions

Natural excipients play a crucial role in maintaining the consistency and stability of liquid dosage forms.
• **For suspensions**, alginates, tragacanth, and xanthan gum are examples of natural polymers that are utilised as suspending agents in suspensions. They make the fluid more viscous and keep insoluble active medication ingredients from settling.

• **For emulsions,** Natural excipients such as lecithin and acacia are utilised as emulsifying agents in emulsions. They prevent each oil and water droplet from coalescing and increase stability by lowering the surface tension between the two phases. [43]

9.4 Controlled Drug Delivery Systems

Due to their biodegradable and biocompatible qualities, natural excipients are becoming more and more significant in complex drug delivery systems.
• Hydrogels: Alginates, chitosan, and carrageenan are examples of natural polymers that create hydrogels. They have the capacity to swell and absorb a significant amount of water. Their response to environmental cues such as pH and temperature makes them useful for targeted delivery systems, wound healing, and controlled and sustained medication release.

10.48047/jocaaa.2024.32.01.93

• Nanoparticles: For targeted drug delivery systems, natural excipients including chitosan, dextran, and gelatin are utilised in nanoparticles.[44]

10. ROLE OF NATURAL EXCIPIENTS IN NOVEL DRUG DELIVERY SYSTEMS

Because of their biocompatibility, degradability, low toxicity, and variety in applications, natural excipients have become more important in the development of many innovative drug delivery systems.

1. Targeted Drug Delivery: Targeted drug delivery methods frequently employ natural excipients such chitosan, alginates, and dextran. Targeted drug delivery techniques employ polymers such dextran, chitosan, and alginates. They can be altered to identify particular cells or tissues. They have the ability to transport the medications to the site of action.

2. Sustained/Controlled Release: In controlled release drug delivery systems, natural excipients such starch, carrageenan, xanthan gum, and guar gum are frequently utilised. In controlled release dosage forms, natural excipients such starch, xanthan gum, carrageenan, and guar gum are frequently utilised. The dose form serves as a barrier for the medication in this administration method. In the dosage form, natural excipients have the ability to build matrices. They have the ability to create gels that serve as a barrier to the drug's release.

3. Mucoadhesive Systems: Excipients like chitosan, pectin, and mucilage are inherently mucoadhesive, which means they may adhere to the body's mucous membranes, such as those of the buccal, nasal, ophthalmic, and gastrointestinal tracts. This allows the drug to be retained in the absorption site for a longer period, thereby increasing the absorption of the drug.

4. Delivery Based on Nanotechnology: The development of drug delivery methods based on nanotechnology, such as nanoparticles, nanogels, and nanofibers, depends heavily on excipients. Excipients including chitosan, gelatin, and dextran are utilised in the creation of nanoparticles that enhance the effectiveness of the drug delivery procedure and shield the medication from deterioration. Because nanoparticles improve a medication's solubility, stability, and permeability, they can be used to create sophisticated drug delivery systems.[45]

10.48047/jocaaa.2024.32.01.93

Figure No. 2 Role of natural excipients in novel drug delivery system.

11. ASSESSMENT AND DESCRIPTION OF NATURAL EXCIPIENTS

1. Physicochemical Properties: Physicochemical Properties: This stage involves assessing colour, taste, odour, pH, solubility, and moisture content. These characteristics aid in determining the substance's identification, purity, and compatibility for particular formulations.

2. Flow Properties: A number of measures, including angle of repose, bulk density, tapped density, Carr's index, and Hausner ratio, are used to quantify flow qualities. These characteristics are essential for preparing tablets and capsules and for mixing.

3. Swelling Index: It is used to gauge how well natural materials like mucilage and gums can absorb water. When evaluating their suitability as tablet disintegrants, this is crucial.

4. Compatibility Studies: In this step, methods including FTIR, DSC, and XRD are used to make sure the drug and excipients are compatible. This is essential for determining stability and preventing any incompatibilities that could jeopardise the effectiveness of the medication.

5. Stability Testing: Stability testing is carried out in a variety of environmental settings, including light, humidity, and temperature.[46]

12. ASPECTS OF REGULATION

1. GRAS (Generally Recognised as Safe) designation: Commonly used natural excipients, including as gums, cellulose, and starches, are typically given this designation. This indicates that they are

10.48047/jocaaa.2024.32.01.93

regarded as safe based on scientific data and past usage. Documentation of the natural excipients is also required, though.[47]

2. Regulatory Bodies' rules (FDA, WHO): The FDA and WHO have established strict rules pertaining to excipient identification, quality, safety, and performance. Compliance with pharmacopoeial standards like USP, IP, and BP is another aspect of these rules. Furthermore, natural excipients must adhere to regulations including toxicity research and Good Manufacturing Practices. Furthermore, natural excipients must adhere to regulations regarding microbiological limits, heavy metals, and pesticide residues. [48]

3. Obstacles to Approval: Natural excipients provide a number of obstacles. The fact that the composition of natural excipients might change based on their geographic location is one of the main issues. Furthermore, natural excipients can change based on harvesting periods and other variables.[49]

13 TRENDS IN RESEARCH AND RECENT ADVANCES

• **Modified Natural Polymers:** To improve their useful qualities, native natural polymers are undergoing chemical and physical modifications. Chitosan, modified starch, and carboxymethyl cellulose are a few examples.
• **Nano-excipients:** Natural excipients such as nanoparticles, nanogels, and nanoemulsions are used in delivery systems based on nanotechnology. They may enhance a drug's solubility, bioavailability, and targeted delivery. In this regard, polymers including chitosan, alginate, and dextran are being extensively investigated as excipients.
• **AI-Assisted Excipient Design:** To cut down on the amount of time needed for the formulation process, artificial intelligence and machine learning algorithms are being used to anticipate whether excipients will work well with medications. The optimal natural excipients needed for the formulation process could be found by using AI algorithms to analyse the data.[50]

• **Green Chemistry Approaches:** In the context of sustainable development, the application of green chemistry approaches in the extraction process is being highlighted. Enzymes, solvent-free extraction, and other methods are being used to lessen the environmental impact.[51]

14. FORTHCOMING PERSPECTIVES

• **Better Standardisation Techniques:** Despite source variability, new technologies are being developed to guarantee the performance, quality, and purity of natural excipients. To guarantee performance, purity, and quality, methods like chromatography and spectroscopy are being developed**.**

• **Hybrid Excipients:** Despite drawbacks like low stability or unpredictability, the combination of natural and synthetic excipients can yield better results while maintaining advantages like biocompatibility.[52]

• **Growth in Biopharmaceutical Applications:** Because natural excipients are non-toxic and biodegradable, their application in biopharmaceuticals such as proteins, peptides, vaccines, and gene therapy is anticipated to grow.

• **Sustainable Pharmaceutical Development:** The demand for natural excipients may rise due to the increased interest in green pharmacy or the substitution of eco-friendly excipients for synthetic excipients derived from petrochemicals.[53]

10.48047/jocaaa.2024.32.01.93

15. CONCLUSION:

Natural excipients, because of their inherent advantages—such as biocompatibility, biodegradability, non-toxicity, and sustainability—have been recognised as viable substitutes for synthetic excipients. The purpose of this review is to highlight the useful potential of natural excipients in pharmaceutical formulations, including sophisticated drug delivery systems and traditional dosage forms. Natural excipients are more suited for pharmaceutical development since they are safer for patients and less harmful to the environment than manufactured excipients. However, by standardising and utilising cutting-edge technology in excipient processing, problems with stability, batch-to-batch reproducibility, and regulatory obstacles must be resolved. Modified natural polymers, nano-excipients, and AI-based excipient design are examples of excipient advancements that expand and improve their potential. With continued research and advancements in technology, natural excipients are likely to find a significant place in the future of drug development, thereby offering safer, more potent, and eco-friendly pharmaceuticals.

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