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Green Materials in Pharmaceuticals

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Keywords

Green materials, Sustainable pharmaceuticals, Biodegradable polymers, Green synthesis, Eco-friendly packaging systems.

Abstract

Green materials are emerging as a critical solution to address the environmental challenges associated with the pharmaceutical industry. These materials, derived from renewable, biodegradable, and eco-friendly sources, are being increasingly adopted to promote sustainability and reduce harmful impacts. Their role spans across several areas in pharmaceuticals, including drug formulation, packaging, synthesis processes, and drug delivery systems. For example, biodegradable polymers are being used as excipients, green solvents are replacing toxic chemicals in synthesis, and bio-based materials are being utilized in medical packaging to minimize plastic waste. However, the industry faces significant challenges in adopting green materials. High production costs, scalability issues, limited availability of suitable raw materials, and the need for optimized processes remain key barriers. Despite these hurdles, green materials have provided effective solutions such as reducing hazardous by-products, enhancing energy efficiency, and improving the biodegradability of pharmaceutical products. Innovations in biopolymers, natural carriers, and eco-friendly synthesis methods demonstrate the potential to revolutionize drug development while minimizing environmental harm. Current challenges include the need for further research to improve the stability and performance of green materials, regulatory complexities, and cost-effective scalability. Moving forward, there is immense scope for advancing bio-based formulations, integrating circular economy principles, and fostering interdisciplinary innovations to fully realize the potential of green materials in pharmaceuticals. Grey areas that require attention include the lack of comprehensive lifecycle assessments, limited industrial awareness, and the absence of standardized guidelines for the widespread adoption of green materials. Addressing these concerns will be crucial to achieving a balance between pharmaceutical innovation and environmental sustainability. By overcoming existing challenges, green materials have the potential to pave the way for a greener, eco-friendly pharmaceutical future.

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1. Introduction

The need for green materials in the pharmaceutical industry arises from the urgent necessity to reduce the sector's environmental footprint, which spans the entire lifecycle of drug development from raw material sourcing to patient use and post-consumption disposal. Pharmaceuticals contribute significantly to environmental pollution through various stages such as synthesis, manufacturing, packaging, and disposal (Kümmerer, 2009). In recent years, pharmaceutical compounds and their metabolites are increasingly identified in environmental matrices, from surface waters to groundwaters and soils, for posing ecological hazards such as toxicity to wildlife, toxicity to aquatic organisms, endocrine disruption, or development of antimicrobial resistance (Patel et al., 2019). Owing to continuous input from manufacturing, patient usage, and improper disposal, they are considered pseudo persistent pollutants whose input rate overwhelms the capacity of wastewater treatment or the treatment systems are not designed to remove them effectively (Miettinen and Khan, 2022).

The green chemistry ethos-that is, the use of renewable feedstocks, biodegradable materials, and benign solvents-has thus entered into pharmaceutical design, aiming to minimize hazardous waste and maximize process sustainability (Green Chemistry Principles)(Kar et al., 2022). Incorporation of green pastes for biomedical formulations where biodegradable biopolymers (such as nanocellulose) and green solvents have been used in drug formulation and delivery lead to an enhanced environmental profile without compromising functionality, thus further confirming their roles in the next-generation pharmaceutics (Garcia et al., 2024).

In particular, this paper will attempt to study the role and types of green materials, biopolymers, green solvents, and nanocarriers in pharmaceutical applications. Their influence on formulations, synthesis, packaging, and delivery systems is thoroughly analysed. Also, technological developments, regulations, and barriers to acceptance are multidimensionally examined. Research gaps are identified, such as lifecycle analyses, industrial awareness, and standardization requirements. The ultimate intention is to map a realistic and actionable pathway for the incorporation of sustainability in pharmaceutical innovation.

2. Green materials: Definition and sources

Green materials are substances intentionally designed and manufactured in alignment with the principles of green chemistry most notably the avoidance of hazardous substances and the prioritization of renewable feedstocks, biocompatibility, and minimal environmental impact (Clark, 2016). These are those that have been obtained from naturally occurring, renewable resources; these have not been known to have any adverse effects on the environment or the eradication of the species, degradation products; their production also employs energy and resource efficient methods including catalysts and biodegradable / non-toxic substances aside from those which are eco-unfriendly / non persistent (Singh, 2022).

In pharmaceutical contexts, green materials which include biodegradable polymers and more natural solvents conceivable in drug development. This is principally because it is characteristic of sustainable pharmaceuticals, as a manufactured goods principle is seen as having a full lifecycle in supplier sustainability (Peake et al., 2016).

The various sources of green material are described below (Fig. 1):

- Plant-Based Polysaccharides
- Chitosan
- Protein-Based biopolymer
- Bio-polyesters
- Green Solvents

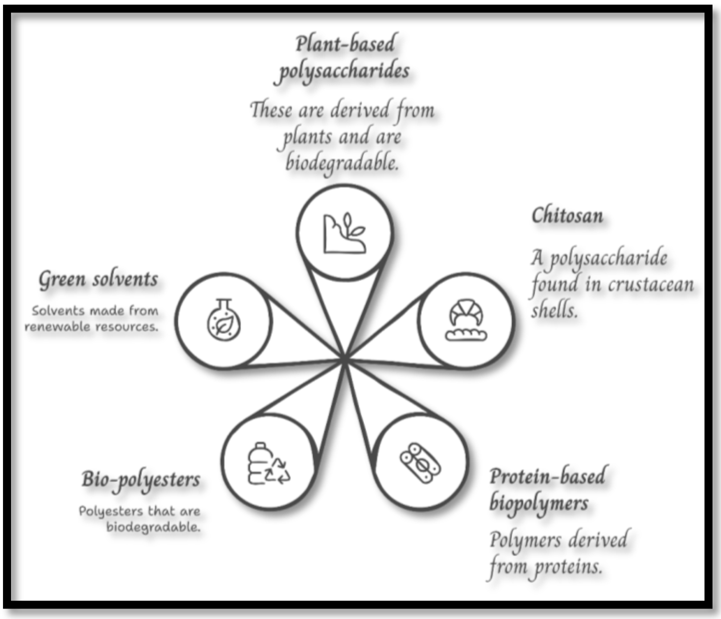

Fig 1: Different Sources of Green material

a) **Plant-Based Polysaccharide:** One of the main classes. They include cellulose, starch, and alginate. These natural polymers are abundant, renewable, and commonly applied as pharmaceutical excipients, drug delivery matrices, and film-forming agents. Cellulose and its derivatives (e.g., hydroxypropyl methylcellulose) are used for controlling drug release, whereas starch and alginate find application in gel formation and mucoadhesion (Arif et al., 2022).
b) **Chitosan:** Another widely used green material comes from deacetylating chitin, which is a polysaccharide found in crustacean shells and fungal cell walls. Chitosan offers biocompatibility, biodegradability, and excellent film-forming and mucoadhesive qualities. These materials have been used in nasal, ocular, buccal, and transdermal delivery systems. Owing to its polycationic nature, chitosan can interact with negatively charged drug molecules or biological membranes, thereby enhancing drug absorption and release control (Serri et al., 2023).
c) **Protein-Based biopolymer:** Polymers like zein (from corn), gelatin (from collagen), and silk fibroin (from the silkworm) are promising contenders for green pharmaceutical services. The versatility of these proteins allows them to create films, hydrogels, and nanoparticles appropriate for drug encapsulation, wound treatment, and tissue engineering. In this context, zein polymer exhibits excellent barrier properties against oxygen, and has high hydrophobicity, making it suitable in controlled release coatings and bioactive films. As with silk fibroin, there is also good mechanical property, slow degradation and controlled structures making it appropriate for members administering injectable depots or implants (Peydayesh et al., 2021).
d) **Bio-polyesters:** The other main source, bio-polyesters, includes polylactic acid (PLA), polyhydroxyalkanoates (PHAs), and poly-caprolactone (PCL). These polymers are derived from either agricultural biomass sources (e.g., PLA from corn starch) or microbial fermentation (e.g., PHAs). PLA is the only polymer approved by the FDA for biomedical applications due to its biodegradability, biocompatibility, and mechanical properties. However, the inherent brittleness and slow degradation of PLA can be modified through copolymerization or blending with other materials.
e) **Green Solvents:** They are thus being promoted as sustainable alternatives to toxic organic solvents used in the synthesis and formulation of pharmaceuticals. These include supercritical fluids (such as supercritical CO_2), ionic liquids, deep eutectic solvents (DES), and biomass-derived solvents like γ-valerolactone (GVL) and 2-methyltetrahydrofuran (2-MeTHF). These solvents present lesser toxicity, possible recycling, and minimal environmental pollution. In more recent times, these environmentally friendly solvents are being utilized in green synthesis, extraction of bioactives, and formulation of drug-loaded nanoparticles (Dolzhenko and Dolzhenko, 2015).

2. Applications of green materials in pharmaceuticals

Green materials offer sustainable alternatives that align environmental responsibility with pharmaceutical efficacy. These are as follows (Fig 2):

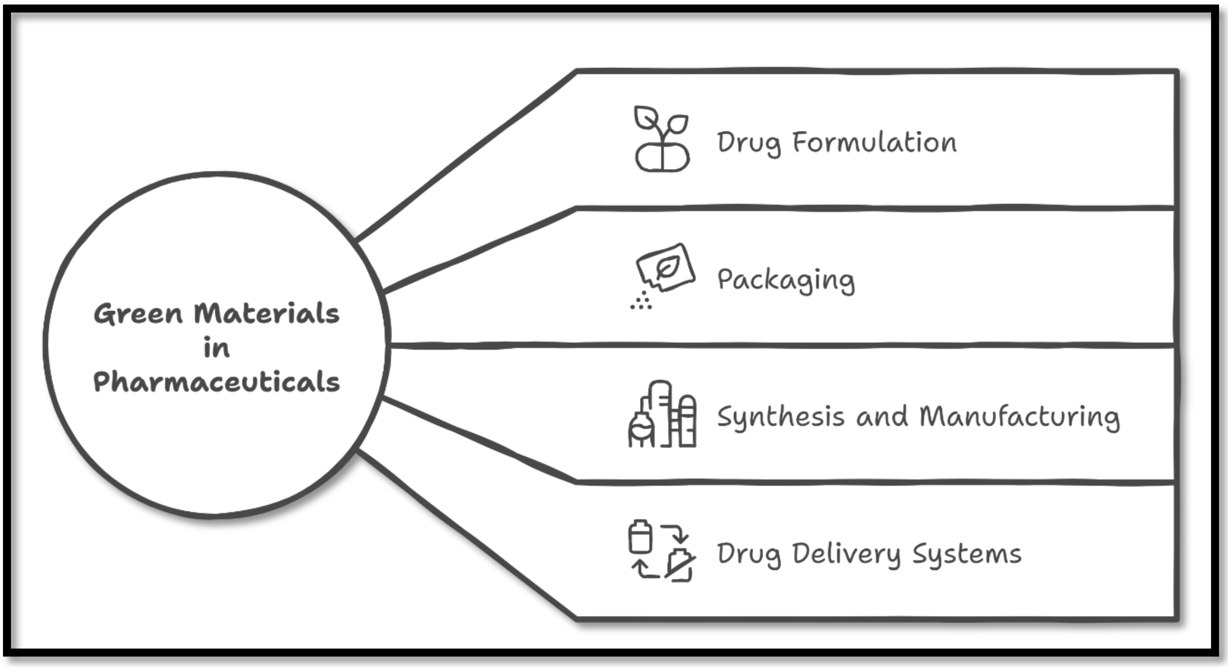

Fig 2: Exploring the Application of Green Materials in Pharmaceuticals

3.1. Drug Formulation

3.1.1. Use of biodegradable polymers as excipients

Biodegradable polymers such as chitosan, alginate, and synthetic polyesters like PLGA and polycaprolactone have established roles as pharmaceutical excipients and formulation matrices. Chitosan functions as a binder, lubricant, and disintegrant in tablets, improves powder flow, and enhances mucosal adhesion, making it useful for oral as well as ophthalmic delivery platforms (Beneke et al., 2009). Alginate forms hydrophilic gels, enabling controlled delivery of peptides and vaccines that resist degradation in the gastrointestinal tract until reaching target sites. Synthetic biodegradable polyesters, including PLGA, PLA, and PCL, are FDA-approved and favoured for controlled-release formulations such as microcapsules, implants, and stents, degrading into non-toxic by-products (Jayapal et al., 2024).

3.1.2. Natural carriers for drug delivery

Natural polymers provide biocompatible and eco-friendly nano-carriers. Chitosan, gelatine, alginate, and albumin have been extensively investigated for nanoparticle and nanocapsule formation due to their biodegradability, low toxicity, and ability to enhance drug bioavailability, targeting, and controlled release(George et al., 2019). For instance, chitosan-tripolyphosphate nanoparticles have been formulated for sustained release of letrozole, while albumin-based carriers (e.g., Abraxane) demonstrate clinical success in targeted cancer therapy(Idrees et al., 2020).

3.2. Packaging

Transitioning to green packaging options is connected with some measurable environmental benefits including less space needed for landfill buildup, avoided microplastics, and alignment with emerging regulations.

3.2.1. Replacement of plastic with bio-based materials

The pharmaceutical sector, which works at the front of technology, is preferring to utilize bio-based polymers over fossil-derived materials like polypropylene (PP) and polyethylene (PE). PLA or poly lactic acid is derived from renewable feedstocks such as corn starch or cane sugar and produces crystalline, clear packaging for blister packs, bottles, and trays, and it is industrially compostable under EN 13432 (Eissenberger et al., 2023). PHA or Polyhydroxyalkanoates, on the other hand, is made by microbial fermentation of sugars, has enhanced biodegradability, including in marine environments, and its mechanical properties may be tailored by changing fermentation parameters (Ashiwaju et al., 2023). In pharmaceutical packaging, PLA-PHA blends serve the double purpose of reducing dependency on fossil plastics while exhibiting better barrier properties, mechanical strength, and biodegradability than neat PLA(Ashiwaju et al., 2023).

3.2.2. Biodegradable and recyclable packaging technologies

Pharmaceutical manufacturers are increasingly adopting biodegradable and recyclable packaging systems with an intention to save the environment and maintain the wary balance of the Circular Economy, as well as to meet regulatory requirements (Swetha et al., 2023). Among the different approaches is starch-based or polysaccharide film development, where such films can be biodegradable and have good film-forming ability with barrier properties tailor-made depending on the blending or chemical modifications, such as phosphorylation or nanoparticle incorporation) (Devi et al., 2025). Such enhancement tends to increase tensile strength, decrease water vapor permeability, and very frequently impart antimicrobial properties, all of which are very important from the standpoint of dosage form stability and safety. The regulatory policies such as EU's directive on the banning of non-compostable plastics by 2030, India's Plastic Waste Management Rules, EPR, etc., support a sustainable alternative by way of banning or EPR (Pei et al., 2024). The above policies are bringing fundamental changes to industry priorities, thereby pushing higher investments on recyclable mono-materials, compostable foams, solvent-free laminates, while also considering lifetime safety and performance. Pharmaceutical companies are now, aside from working on material innovation, also employing biodegradable packaging in the real world (Dhalsamant et al., 2025). For example, Astellas Pharma, which released blister packs made from sugarcane-derived biomass, achieving a potential decline in greenhouse gas emissions against those created with conventional plastics. Other examples of recent technological developments are paperboard cartons glued together without the use of harmful solvents and aluminium foils that are largely recyclable and maintain barrier properties to reduce environmental impacts while safeguarding the drug quality (Fatima et al., 2024).

3.3. Synthesis and Manufacturing

3.3.1. Use of green solvents and eco-friendly reagents

Expanding on the concepts of green chemistry, green solvents, and environmentally friendly reagents, the pharmaceutical sector has gained momentum in minimizing hazardous waste and ensuring safety in the manufacture of active pharmaceutical ingredients (APIs). Being obtained from lignocellulosic biomass, γ-valerolactone (GVL) is an ecologically friendly, non-toxic, high-boiling, and biodegradable solvent and has proven very good for hydrogenation and enzymatic transformations(Bandichhor et al., 2013). 2-Methyltetrahydrofuran (2-MeTHF) and cyclopentyl methyl ether (CPME), being environmentally-friendly aprotic solvents, have also been proposed by the pharmaceutical roundtable to replace volatile organic compounds so as to decrease process mass intensity (PMI), increase atom economy, and improve recyclability during industrial syntheses of APIs like dimethindene (Quivelli et al., 2022). Deep eutectic solvents (DESs) and ionic liquids (ILs) based on natural compounds such as choline chloride, urea, or sugars give biodegradable, low-toxicity options for protection and extraction reactions (Scarpelli et al., 2024). With such solvent systems, it becomes possible to apply green chemistry principles and enhance solvent recyclability, decrease emissions, and provide safer working environments for pharmaceutical manufacture.

3.3.2. Greener synthesis routes and process chemistry

In parallel with the deployment of green solvents, the greener synthesis strategies are revolutionizing API production via innovative routes that promote atom economy and decrease by-products and energy consumption. The main emphasis in the Chemical Reviews was laid on one-pot syntheses, multicomponent reactions (MCRs), continuous flow processing, and enzymatic catalysis to curtail the wastes and simplify pharmaceutical manufacturing (Kar et al., 2022). Synthetic routes involving supercritical fluids such as CO_2 and water impart solvent-free or low impact methods for materials and intermediates with high yields and simplified purification. Use of solid supported catalysts, e.g., zeolites and clays along with solvent-free techniques such as ball milling and microwave open up possibilities of further reduction in solvent usage and reduction in hazardous by-products (Kharissova et al., 2019). Case studies such as enzymatic, solvent-free artemisinin synthesis and biocatalyzed continuous-flow platforms have also been launched by pharmaceutical groups to demonstrate effective alignment with the green chemistry metrics while maintaining a high standard of quality (Dolzhenko and Dolzhenko, 2015). These greener process not only lower environmental footprints but also shorten production timelines and reduce manufacturing costs.

3.4. Drug Delivery Systems

3.4.1. Biodegradable and targeted delivery platforms

Now, imparting controlled release profiles, biocompatibility, and site-specific targeting, biodegradable polymeric nanoparticles, microspheres, and capsules seem to be the staples of contemporary drug delivery avenues. Natural and synthetic polymers, including chitosan, PLGA, PCL, and albumin, are utilized for the synthesis of degradable nanocarriers that slowly lose their integrity in vivo to oftentimes release drugs in a sustained manner or simply target a site of interest for release of the payload. PLGA, which is a copolymer of lactic and glycolic acids, is one of the FDA-approved biodegradable carriers commonly used for delivery of chemotherapy agents, vaccines, and peptide drugs. By changing their lactide-glycolide ratios and molecular weight, the degradation time and release kinetics of the drug from the carrier can be precisely controlled (Gagliardi et al., 2021). Letrozole was released in a controlled manner with encapsulation efficiencies higher than 80 % and prolonged circulation time of the drug using chitosan-tripolyphosphate NPs (Geszke-Moritz and Moritz, 2024; Tan et al., 2022). Protein polymers are exploited in albumin-based carriers, such as Abraxane, to target the delivery of paclitaxel and reduce its systemic toxicity. Furthermore, novel biodegradable platforms such as cross-linked mastic gum nanoparticles have been developed for site-specific colon delivery of 5-FU, releasing more than 95 % of the drug in the colon following zero-order kinetics, thereby minimizing off-target effects and maximizing therapeutic efficacy (Idrees et al., 2020).

3.4.2. Environment-responsive materials

Environment-responsive or "smart" drug delivery materials respond to physiological stimuli such as pH, temperature, ionic strength, or external triggers to unleash a therapeutic load where and when needed. pH-responsive microgels and hydrogels such as poly (methacrylic anhydride) coatings and stimulus-sensitive cellulose hydrogels offer controlled release profiles that protect drugs from stomach acid and trigger delivery in the targeted intestinal region. Conversely, pH-responsive nanoparticles induce structural changes (e.g., swelling, charge switching, or disassembly) under acid conditions within tumour microenvironments or specific organelles to enhance intracellular drug delivery and reduce off-target toxicity (Shi et al., 2018). For example, acid-degradable polyanhydride membranes allow delayed drug release in neutral-to-basic environments (e.g., intestines) while maintaining stability in the acid conditions of the stomach (Tan et al., 2022). Other stimuli-responsive systems include thermoresponsive hydrogels (such as PNIPAM-based matrices), which shrink when heated and swell when cooled, thus exerting an "on–off" control over release (Qiu and Park, 2012). Under this same principle, magnetic-sensitive hydrogels, etched with iron oxide nanoparticles, could be used for externally controlled release of drugs upon exposure of the alternating magnetic field (Hernández et al., 2010). The nanodroplets, having a dual resonance feature, formed by gelatin-perfluorohexane, trigger the release of therapeutic molecules, such as berberine, through acid-ultrasound stimulation with over 89 percent of release after ultrasonication activation (Givarian et al., 2024).

4. Environmental and industrial benefits

The adoption of green materials and practices in pharmaceutical manufacturing yields significant environmental and industrial advantages (Fig 3):

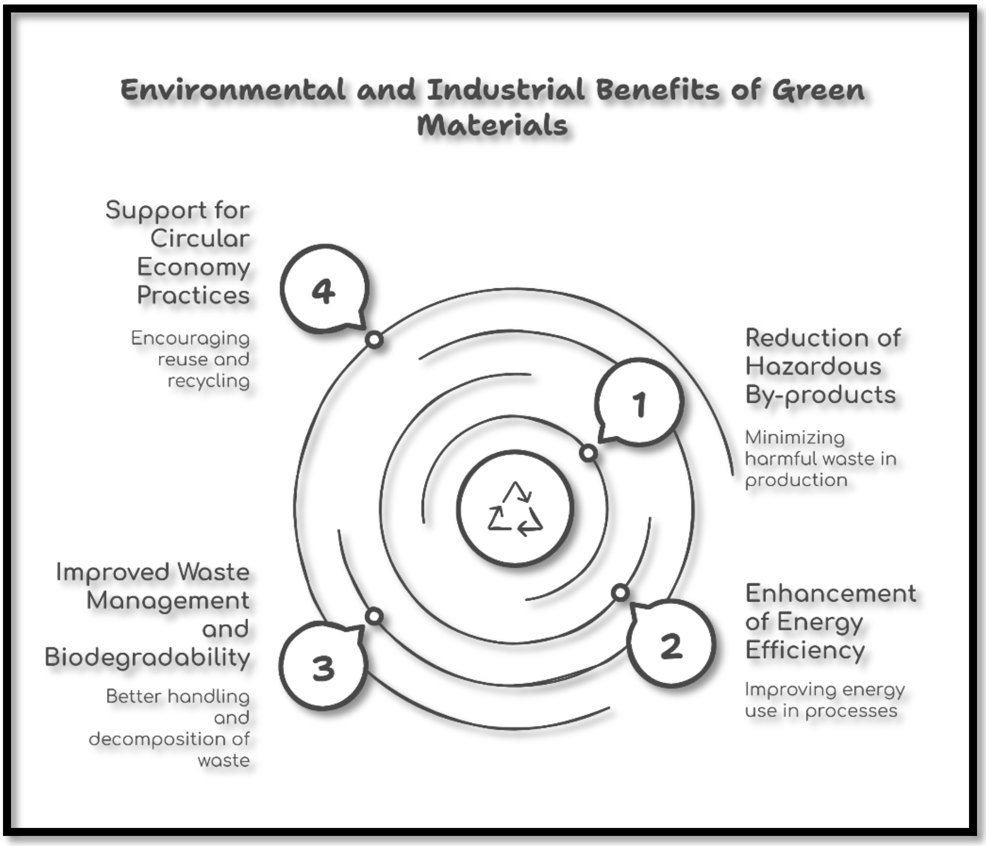

Fig 3: Benefits of Green Material to Environment and Industry

4.1. Reduction of hazardous by-products

The generation of hazardous waste has been greatly minimized by green chemistry practices such as atom economy, catalysis, and solvent exchange (Moermond et al., 2022). Merck's biocatalytic synthesis of sitagliptin is a classic case where wastes were diminished by approximately 220 lbs per lb of the product, with many of the harmful reagents and intermediates being eliminated. Similarly, Pfizer's green chemists found ways to reduce total waste by 50% and greatly reduce unwanted chemical by-products (Industry Takes Steps Toward Greener API Manufacturing, n.d.).

4.2. Enhancement of energy efficiency

Introducing biocatalysts, continuous-flow processing, and solvent-less methods has contributed to energy reduction in drug synthesis by facilitating inventions that can carry out reactions at room temperature and ambient pressure, with fewer steps (Sheldon, 2016). Flow photochemistry and enzymatic routes are a couple of examples that show pharmaceutical processes can be carried out with a lesser impact on energy, in keeping with one of the principles of green chemistry which aims at energy efficiency (Sustainability | Special Issue : Advancing Green Chemistry in Bio-Circular Economies: Sustainable Solutions for Waste Valorization and Resource Efficiency, n.d.)

4.3. Improved waste management and biodegradability

Use solvent-recovery methods like distillation and membrane filtration to recover costly solvents, which also reduces volumes of wastes and disposal charges. This further promotes ecosystem-friendly degradation of pollutants through improved pharmaceutical wastewater treatments having biochar and photocatalytic methods (S. Sharma et al., 2020).

4.4. Support for circular economy practices

Pharma companies are implementing circularity concepts by solvent recycling, biomass valorization, and closure of material loops. The evolution from a linear to circular approach is affirmed, joining solvent recycling, upcycling of agricultural residues, and bio-based feedstocks that connect pharmaceutical production into the larger biorefinery ecosystem (Salmenperä et al., 2022).

5. Challenges and limitations

Implementing green materials in pharmaceuticals offers promising sustainability benefits, yet several critical barriers remain. These are described under (Fig 4):

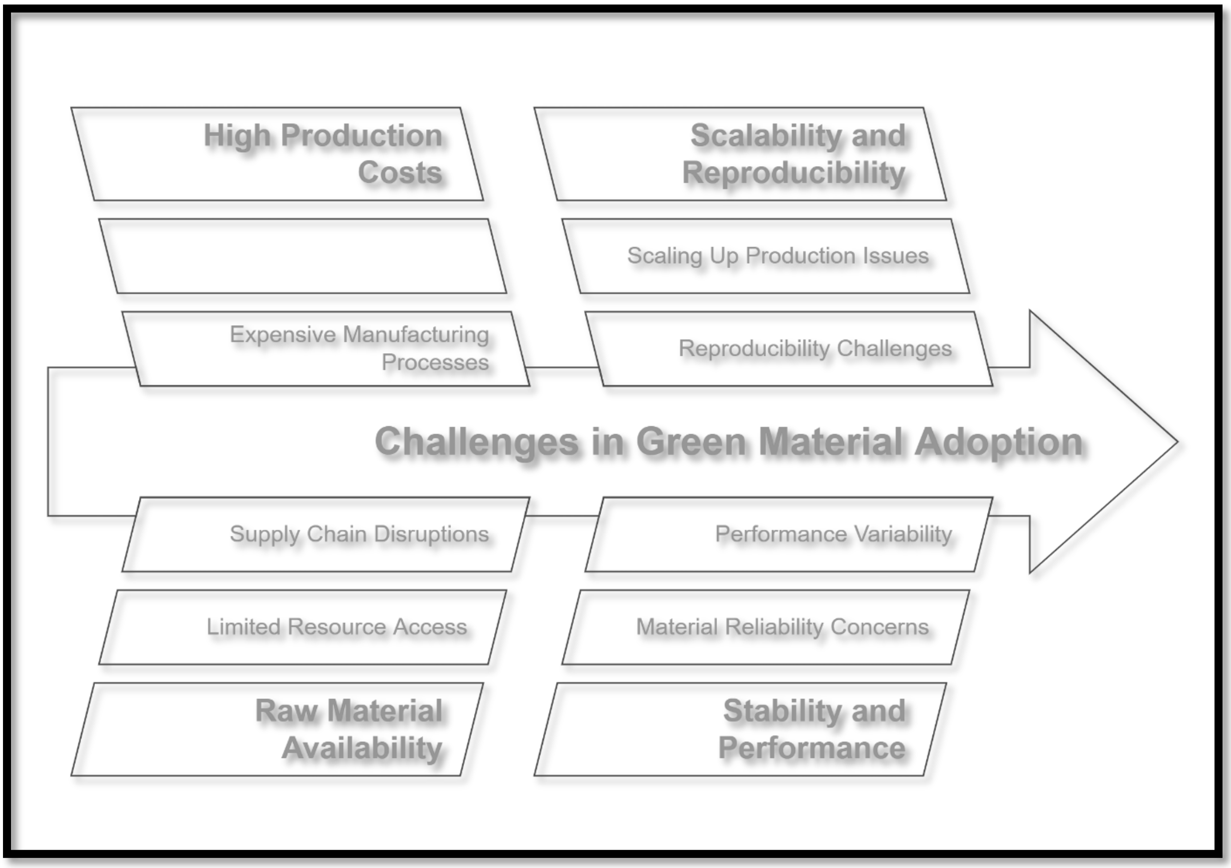

Fig 4: Various Challenges Faced in Green Material Adoption

5.1. High production and processing costs

On the other hand, green technologies usually require higher capital investment prior to operations, special equipment, and substantial investment into development and regulatory processes. According to a descriptive review by MDPI, capital investment including fixed costs, research, regulatory documentation is estimated to comprise most of the total implementation costs, with ongoing variable costs, e.g., yield efficiency or reagent price, being critical to long-term economic viability (Cravotto, 2025; Palma and Hodgett, 2025). Hence, the investment required can sometimes pose as an obstacle, especially for biotech start-ups and smaller manufacturers, that might not be able to justify the expense upfront despite probable future-saving potentials.

5.2. Raw material availability and supply chain issues

The inconsistencies in the feedstock and reagents with sustainable origins necessitate a steady supply to maintain quality standards. Responding to the sourcing-transparency issue, the pharmaceutical industry's somewhat conventional supply chains scattered all over the globe do not integrate new materials into the solution, since issues regarding the shadow of doubt on the latter directly concern doubts about the quality of the guarantees and deadlines that must be met. Alternatively, for an item to be widely used, consistent spec limits and limits need to be provided by agricultural or biomass-derived feedstocks (Pereira and Cotas, 2024).

5.3. Scalability and reproducibility in industrial settings

Scale-up is the stumbling block for many green chemistry innovations. According to a review, scale-up contributes toward process complexities in reaction kinetics, mixing, heat transfer, and mass-transfer that commonly alter yields and waste profiles, unless properly reengineered (Cravotto, 2025). Furthermore, the pharmaceutical industry's risk-averse culture combined with strict GMP and regulatory requirements, are factors that tend to slow down the adoption of new technologies such as continuous-flow reactors or enzymatic processes (Cohen et al., 2023).

5.4. Stability and performance concerns of green materials

Compared to synthetic polymers, green polymers or bio-carriers prove inferior to the pressure of mechanical strength or barrier properties or stability under given conditions. They inhibit example: PLA-like biodegradable plastics generally cannot withstand too much moisture absorption and possess low durability unless modified, but such modifications may affect the biodegradability. In pharma, where integrity of dosage and shelf life hold to stringent standards, any deviation from specification becomes a critical issue (Helanto et al., n.d.).

6. Future directions and opportunities

With a strong global focus on sustainable healthcare, the future of green materials in pharmaceuticals is full of opportunities. The development of bio-based formulations will be one of the most critical aspects of this future, allowing drug development and delivery to be greener by following the principles of green chemistry and circular economy. The biopolymers considered here include cellulose, starch, polylactic acid (PLA), and polyhydroxyalkanoates (PHAs), which are considered favourable for controlled release systems of drugs due to their biodegradability, biocompatibility, and renewable nature-from agricultural or microbial sources(M. Sharma et al., 2021). In a similar way, within the pharmaceutical production chain, attempts are ongoing for solvent recycling, biodegradable packaging, green synthesis processes, and biomass valorisation. For instance, drug packaging is being designed by companies using compostable or recyclable materials like blister packs made from polylactic acid or alginate-based films, which is a major atmospheric reduction of persistent plastic waste. Green initiatives for the recovery of solvents in API manufacturing are also being seen as environmentally and economically sound ways of minimizing hazardous wastes and reducing operational costs.

The very realization of these sustainable targets, however, requires strong interdisciplinary integration. Chemists and material scientists, process engineers, environmental biologists, and regulatory experts must collaborate to design, validate, and commercialize green technologies that can meet requirements and standards pertaining to pharmaceutical quality, and this collaborative environment will nurture further dialog on defining common sustainability metrics and regulatory pathways necessary for green materials to gain higher industrial acceptance. Driven by the Green Deal, the push from regulatory agencies such as FDA and EMA is now towards making environmental impact assessments a part of pharmaceutical submissions, further reinforcing the shift toward greener practices.

Despite these promising advances, it remains an overriding challenge to commercialize green technologies originating from laboratories. Scalability can be hindered by problems such as inconsistent raw material quality, variable processes, and production costs. To overcome these obstacles, in recent research, enzyme-assisted polymerization, microbial biorefineries, and aqueous-based synthesis methods are studied so as to enable greener chemical production with lower energy inputs and higher process efficiency(Babu et al., 2013). In the future, investing more in green material infrastructure, regulatory harmonization, and public-private partnerships will be required to facilitate green technology scale-up and standardization. Green materials will move from being a moral or environmental issue to being a strategic and competitive imperative as sustainability increasingly becomes a key performance indicator in pharmaceutical manufacturing. Their adoption will represent a complete change in how medicines are developed, delivered, and disposed of, leading to a green pharmaceutical innovation era that protects both human and planetary health.

7. Conclusion

Green materials present a revolutionary opportunity to merge pharmaceutical development with sustainability, safety, and environmental stewardship. Pharmaceutical formulation and packaging, synthesis, and delivery include materials such as biopolymers, green solvents, and responsive systems. These materials truly provide opportunities to dispose of lesser hazardous waste, conserve energy, offer better biodegradability, and support circular economy concepts. However, some concerns stop these materials from going fully mainstream: production costs, raw material availabilities, and scale-up issues, together with inconsistent performance.

Given the increasing environmental and regulatory pressures faced by the pharmaceutical sector, it has become a crucial strategic choice, rather than just the sustainable choice, for critical long-run resilience and innovation. If the present limitations are overcome through interdisciplinarity and never-ending innovation, green materials shall be able to lead the way in ushering the pharmaceutical world toward a greener, more responsible future.

List of Abbreviations

1. PLA - Polylactic acid
2. PHAs - Polyhydroxyalkanoates
3. PCL - Polycaprolactone
4. PHB - Poly3-hydroxybutyrate
5. FDA - Food and Drug Administration
6. DES - Deep eutectic solvents
7. GVL - Gamma (γ) valerolactone
8. 2-MeTHF- 2-methyltetrahydrofuran
9. PLGA - Poly lactic-co-glycolic acid
10. PP - Polypropylene
11. PE - Polyethylene
12. EUs - European Union
13. PMI - Poly Mass Intensity
14. APIs - Active Pharmaceutical Ingredient
15. CPME - Cyclopentyl methyl ether
16. ILs - Ionic Liquids
17. MCRs - Multicomponent reactions
18. NPs - Nanoparticles
19. 5- FU - 5-Floro Uracil
20. PNIPAM - Poly(N-isopropylacrylamide)
21. GMP - Good Manufacturing Practices
22. EMA - European Medical agency

Conflict of Interest

The authors declare that there are no conflicts of interest related to the content of this manuscript.

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Authors Contribution

Mr. Abhishek Chandola is the principal author of this article who has conceptualized, drafted and has written this manuscript. Dr. Ujjwal Nautiyal, and Mr. Rahul Pandey have played a huge role in critical revision, content refining and continuous reviewing of the manuscript at various stages, for enhancing the quality of the manuscript.

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