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Review Article

Shellac as a renewable natural resin for pharmaceutical and biomedical applications: Properties, modification strategies, and emerging technologies

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ABSTRACT

Shellac is a renewable natural resin secreted from the lac insect "*Kerria lacca*". According to its excellent film-forming ability, moisture-protective properties, thermoplastic behavior, and pH-responsive dissolution, shellac has been conventionally employed as a pharmaceutical enteric coating material. Nevertheless, its broader application is limited by several inherent drawbacks, including film brittleness, hydrophobicity, relatively slow dissolution at intestinal pH, and progressive loss of solubility during storage. This review discusses the chemical composition and physicochemical properties of shellac, with particular emphasis on strategies developed to overcome these limitations. These approaches include partial hydrolysis, salt formation, esterification, plasticization, polymer blending, particle engineering, and controlled thermal processing. In addition to its established use in enteric and colon-targeted drug delivery, shellac has been incorporated into floating dosage forms, micro- and nanoparticulate carriers, periodontal in situ delivery systems, biodegradable implants, wound dressings, and controlled-release formulations. More recently, its thermoplastic processability and pH-responsive characteristics have enabled its application in hot-melt extrusion and fused deposition modeling three-dimensional printing for the fabrication of personalized and site-specific drug delivery systems. Collectively, these developments demonstrate that shellac is not merely a traditional coating material but a versatile and sustainable platform for advanced pharmaceutical manufacturing and biomedical applications.

Keywords:
Natural resin; Drug delivery; Biomedical applications; Hot-melt extrusion; Three-dimensional printing

1. INTRODUCTION

Shellac is a naturally derived resin obtained from the resinous secretion produced by the female lac insect *Kerria lacca* on various host trees. It is a chemically heterogeneous and polydisperse material composed predominantly of short-chain polyesters and monoesters formed from hydroxy fatty acids and sesquiterpenoid acids, particularly aleuritic acid and shellolic- and jalaric-type acids. This distinctive chemical architecture gives shellac a combination of valuable functional properties, allowing it to serve as a film-forming agent,

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moisture barrier, thermoplastic material, and pH-responsive polymer [1,2].

For pharmaceutical applications, shellac is among the earliest natural polymers employed as an enteric coating material because of its low solubility under acidic conditions and increased solubility at neutral to alkaline pH. Nevertheless, its performance is constrained by several inherent limitations, including relatively slow dissolution at intestinal pH, progressive loss of solubility during storage due to further esterification and crosslinking, and the brittleness of unmodified films. To overcome these drawbacks and improve its physicochemical and functional performance, a range of chemical and physical modification strategies has been investigated. These include partial hydrolysis, salt formation, esterification with cyclic anhydrides, plasticization, polymer blending, particle-size reduction, and composite fabrication [1–7].

Modification strategies for shellac can be classified according to their underlying molecular mechanisms. Partial hydrolysis cleaves ester linkages within the polymer structure, thereby increasing the density of free carboxylic acid groups. The resulting increase in ionizable groups promotes polymer hydration and enhances pH-dependent dissolution. However, excessive hydrolysis may weaken intermolecular cohesion, producing softer films with reduced mechanical integrity [3]. Salt formation converts carboxylic acid groups into carboxylate species, which increase polymer ionization, facilitate chain separation, and improve both dissolution and storage stability [5]. Esterification with cyclic anhydrides, such as succinic anhydride or phthalic anhydride, introduces additional pendant carboxylic acid groups into the shellac structure, thereby enhancing ionization and promoting dissolution at intestinal pH while maintaining resistance under gastric conditions [4,8]. Plasticization increases polymer-chain mobility, improves film flexibility, and delays storage-induced embrittlement; however, highly hydrophilic plasticizers may compromise the moisture-barrier properties of shellac films [6]. In addition to chemical modification, polymer blending and composite formation can further tailor porosity, swelling behavior, mechanical strength, bioadhesion, and antimicrobial functionality. Particle-size reduction enhances dissolution by increasing the surface area available for interaction with the dissolution medium. In contrast, thermal curing or annealing promotes controlled esterification and crosslinking within the shellac matrix, thereby improving water resistance and structural integrity, although excessive crosslinking may reduce the dissolution rate [7].

The applications of shellac have evolved from traditional industrial uses to advanced biomedical applications. From its established roles in industrial coatings, food applications, and pharmaceutical formulations, shellac has evolved into a versatile biomaterial for enteric and colon-targeted drug delivery, matrix-based delivery systems, micro- and nanoparticulate carriers, electrospun nanofibers, wound dressings, biomedical coatings, and multifunctional bioactive composites.

The applications of shellac have expanded considerably beyond its traditional use in industrial coatings, food products, and conventional pharmaceutical formulations. It is now increasingly investigated as a versatile biomaterial for enteric and colon-targeted drug delivery, matrix-based systems, micro- and nanoparticulate carriers, electrospun nanofibers, wound dressings, biomedical coatings, and multifunctional bioactive composites.

Emerging research has further focused on integrating shellac with advanced manufacturing technologies, particularly hot-melt extrusion and additive manufacturing. Its thermoplastic processability, pH-responsive dissolution, film-forming capacity, and chemically modifiable structure make shellac a promising material for the development of composite nanofibers, particulate carriers, biomedical coatings, and multifunctional drug delivery platforms. In particular, shellac-based filaments and printable polymer blends have potential for fused deposition modeling three-dimensional printing, enabling the fabrication of personalized and site-specific dosage forms with tunable release characteristics.

2. SHELLAC: ORIGIN, CHEMISTRY, AND PROPERTIES

Shellac is the refined resin obtained from lac, a resinous secretion produced by the female lac insect *Kerria lacca* on host trees, as illustrated in Figure 1. Its chemical composition and material quality are influenced by several factors, including the insect strain, host plant species, harvesting conditions, and subsequent purification processes. Traditionally, shellac has been used as a protective coating and natural adhesive in numerous industrial products. More recently, its renewable origin, film-forming ability, and functional versatility have stimulated growing interest in its use in pharmaceutical, biomedical, food, and packaging applications [1,2,5].

Chemically, shellac is a heterogeneous polymeric resin comprising a hard-resin fraction composed predominantly of short-chain polyesters and a soft-resin fraction containing various monoesters derived from hydroxy fatty acids and sesquiterpenoid acids (Figure 2). Aleuritic acid is the major hydroxy fatty acid constituent, whereas shellolic, jalaric, and laccijalaric acids represent the principal sesquiterpenoid acid components. This complex polyester-based structure gives shellac both hydrophobic

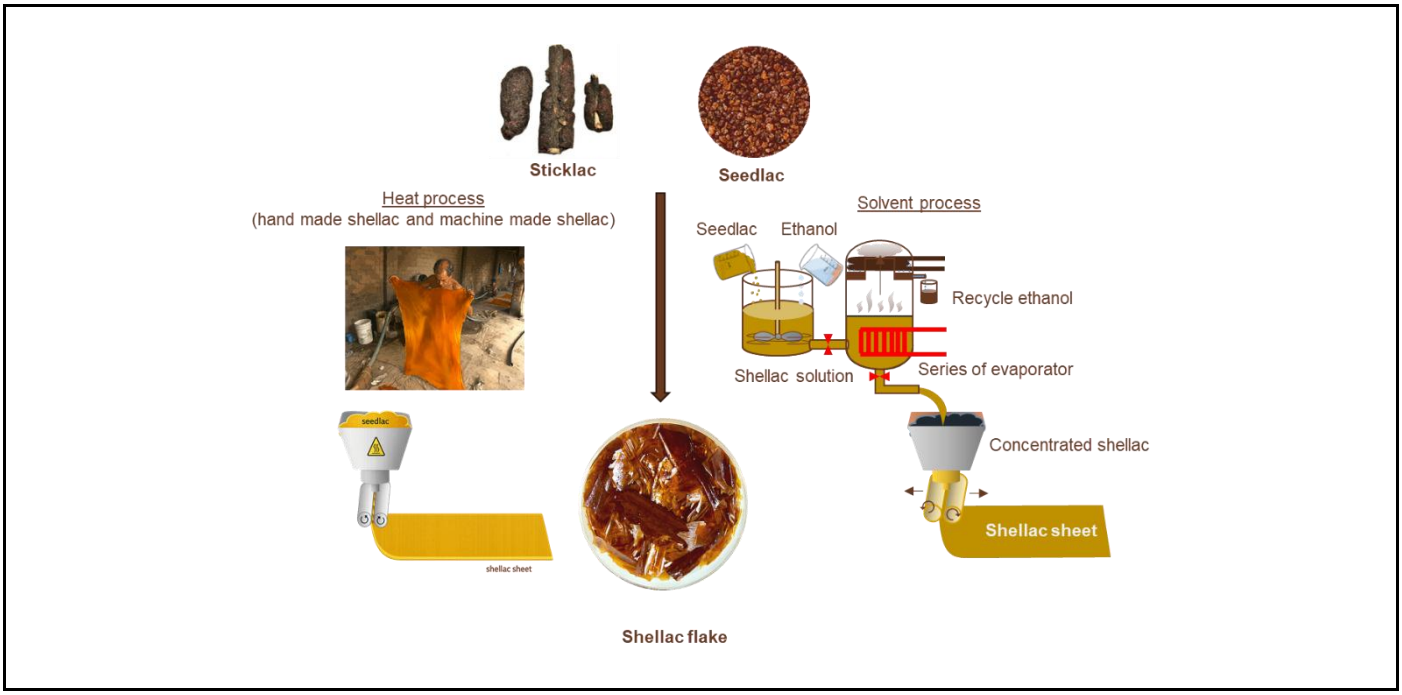

Figure 1. Preparation process of shellac.

and ionizable characteristics. Its hydrophobic moieties contribute to water resistance, surface gloss, and moisture-barrier performance, whereas the free carboxylic acid groups govern its pH-responsive dissolution behavior. Accordingly, shellac remains sparingly soluble under acidic conditions but becomes increasingly soluble at neutral to alkaline pH as the carboxylic acid groups ionize, promoting polymer hydration and chain separation. These physicochemical properties enable shellac to function as a film-forming agent, moisture barrier, natural adhesive, and pH-responsive polymer. Its pH-dependent dissolution has therefore been widely exploited in enteric coating systems and also supports its application in colon-targeted drug delivery [1,2,5,9].

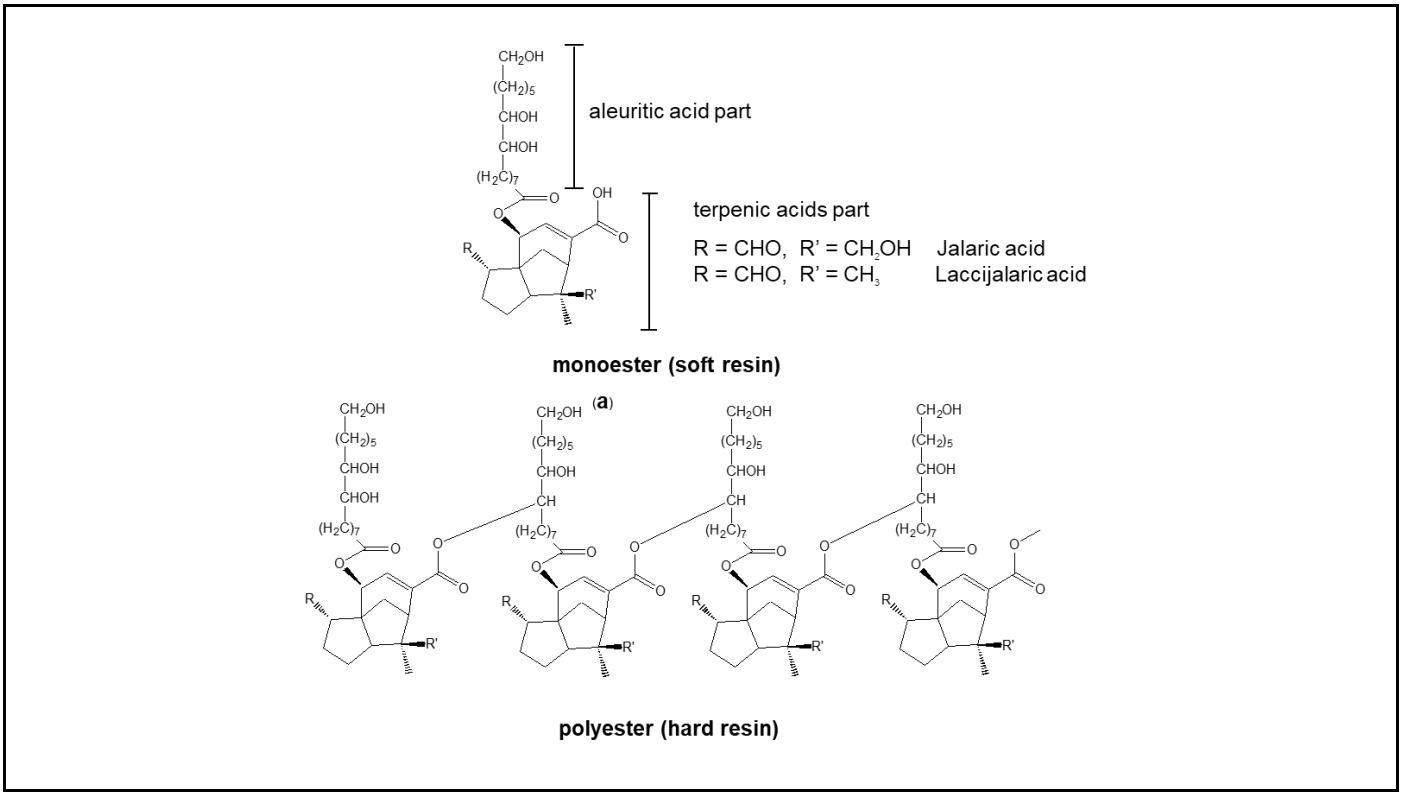

Figure 2. Chemical structure of shellac component.

In addition to its pH-responsive dissolution, shellac is readily soluble in several organic solvents, particularly lower alcohols such as ethanol. This property facilitates the preparation of shellac coatings by conventional solvent-casting and coating techniques. In contrast, aqueous processing generally requires prior neutralization of the free carboxylic acid groups with ammonium, amine, or alkali bases to form water-soluble shellac salts. The choice of solvent system also affects the physicochemical properties of the resulting films. Compared with alcohol-cast films, films prepared from alkaline aqueous solutions typically exhibit higher water-vapor permeability because salt formation increases polymer hydrophilicity and promotes water uptake [5].

Thermally, shellac exhibits thermoplastic behavior, with a glass-transition temperature (T_g) of approximately 38–42 °C, depending on its grade, composition, and wax content. Prolonged exposure to elevated temperatures promotes further esterification and the formation of a more densely interconnected polymer network. These structural changes restrict polymer-chain mobility, thereby enhancing thermal stability, water resistance, and mechanical rigidity while increasing the T_g to approximately 77–90 °C. However, excessive thermal treatment may reduce shellac solubility and retard subsequent drug release [7,10].

Despite its favorable physicochemical properties, native shellac presents several inherent limitations, including relatively slow dissolution at intestinal pH, brittleness of unmodified films, and progressive esterification and network formation during storage, which gradually reduce its solubility. Moreover, variations in biological source, processing conditions, and purification procedures can result in differences in chemical composition and material performance. These limitations have stimulated extensive research into chemical, physical, and structural modification strategies designed to improve the dissolution, mechanical properties, processability, and storage stability of shellac while retaining its advantages as a renewable natural polymer.

3. MODIFICATION STRATEGIES OF SHELLAC

To broaden the practical applications of shellac, numerous modification strategies have been developed to tailor its physicochemical, mechanical, and functional properties. Based on their underlying mechanisms, these approaches can be broadly classified into chemical and physical modifications.

3.1. Chemical modification

Partial hydrolysis is among the most extensively investigated chemical modification strategies for shellac. During controlled alkaline hydrolysis, a proportion of the ester linkages within the polymer structure is cleaved, thereby increasing the concentration of free carboxylic acid groups. These groups ionize more readily at intestinal pH, promoting polymer hydration, chain separation, and dissolution. Partial hydrolysis can also increase film elongation; however, this improvement in flexibility is generally accompanied by a reduction in tensile strength. Excessive hydrolysis may further weaken intermolecular cohesion, resulting in softer films with diminished mechanical integrity, reduced moisture-barrier performance and compromised storage stability. Additionally, the stability of shellac is also diminished. Therefore, the degree of hydrolysis must be carefully optimized to enhance pH-dependent dissolution while maintaining adequate mechanical strength and film functionality [3].

Another effective chemical modification strategy is salt formation, in which the free carboxylic acid groups of shellac are neutralized with ammonium, amino alcohol, or alkali bases to form carboxylate salts. This conversion increases polymer ionization, thereby improving aqueous processability, dissolution at intestinal pH, and storage stability. Mechanistically, carboxylate formation enhances polymer hydration and promotes separation of adjacent polymer chains. In addition, sterically bulky counterions, such as 2-amino-2-methyl-1-propanol (AMP), may further reduce intermolecular association and limit storage-induced esterification and network formation. However, the increased hydrophilicity associated with salt formation may compromise the water- and moisture-barrier properties of shellac films. Salt formation is therefore particularly advantageous for aqueous formulations and applications requiring enhanced or more rapid dissolution, whereas alcohol-based processing may remain preferable when superior moisture resistance is a primary requirement [5].

Esterification with cyclic anhydrides, particularly succinic and phthalic anhydrides, has also been investigated as a strategy for improving shellac performance. During solid-state esterification, the cyclic anhydrides react with hydroxyl groups in the shellac structure, introducing additional pendant carboxylic acid groups and forming shellac succinate or shellac phthalate derivatives. The increased density of ionizable groups enhances polymer hydration and dissolution at intestinal pH while preserving resistance under gastric conditions. Shellac phthalate has been reported to exhibit greater storage stability than shellac succinate, possibly because the bulky aromatic phthalate groups reduce intermolecular association and limit storage-induced esterification. However, anhydride modification may reduce the mechanical strength of the resulting films; therefore, increased coating thickness or further formulation optimization

may be necessary to maintain adequate film integrity. Overall, esterification with cyclic anhydrides represents an effective approach for improving the pH-responsive performance and storage stability of shellac-based enteric coatings [4,8].

3.2. Physical modification

Besides chemical modification, the addition of plasticizers enhances the flexibility and processability of shellac films by reducing intermolecular interactions between polymer chains and increasing polymer chain mobility, thus reducing brittleness and improving handling characteristics. Among the available plasticizers, low-molecular-weight polyethylene glycols (PEGs), such as PEG 200 and PEG 400, are more efficient plasticizers than high-molecular-weight PEGs, such as PEG 4000, due to their ability to readily intercalate between polymer chains, thereby improving flexibility and storage stability. In contrast, high-molecular-weight PEGs can adversely affect the stability of shellac formulations. However, the moisture-barrier properties of shellac can be impaired by the use of highly hydrophilic plasticizers. Therefore, the type and concentration of plasticizers should be optimized according to the intended application [6].

Thermal processing has emerged as a promising modification strategy for tailoring the physicochemical properties of shellac. Upon heating above its glass transition temperature, shellac exhibits thermoplastic behavior and can be readily processed. However, prolonged heating at elevated temperatures promotes polycondensation between hydroxyl and carboxylic acid groups, resulting in the formation of additional ester linkages and a lightly crosslinked polymer network. These structural changes improve water resistance, thermal stability, and the mechanical integrity of shellac. In addition, the glass transition temperature increases from approximately 42 °C for native shellac to 77–90 °C after thermal curing, indicating enhanced polymer network rigidity and reduced polymer chain mobility. Nevertheless, excessive crosslinking may retard dissolution and delay drug release. Therefore, appropriate thermal treatment can improve the performance of shellac while broadening its applicability in moisture-resistant coatings, adhesive materials, and related applications [7,10].

Blending shellac with hydrophilic polymers, such as poly(vinyl pyrrolidone) (PVP), hydroxypropyl cellulose (HPC), hydroxypropyl methylcellulose (HPMC), polyethylene glycol (PEG), and chitosan, improves its dissolution, swelling behavior, mechanical properties, flexibility, and bioadhesion. Furthermore, incorporating bioactive compounds expands the functionality of shellac for pharmaceutical and biomedical applications. The preparation of shellac as micro- or nanoparticles through electrospraying elevates the specific surface area, shortens diffusion pathways, and improves drug release characteristics. Recently, electrospinning has emerged as a potential technique for fabricating shellac-based nanofibers with high surface area and interconnected porous structures. These electrospun nanofibrous systems have demonstrated considerable effective for controlled drug delivery, antimicrobial materials, and wound dressing applications, especially when incorporated with bioactive agents or blended with complementary polymers [6,11–14].

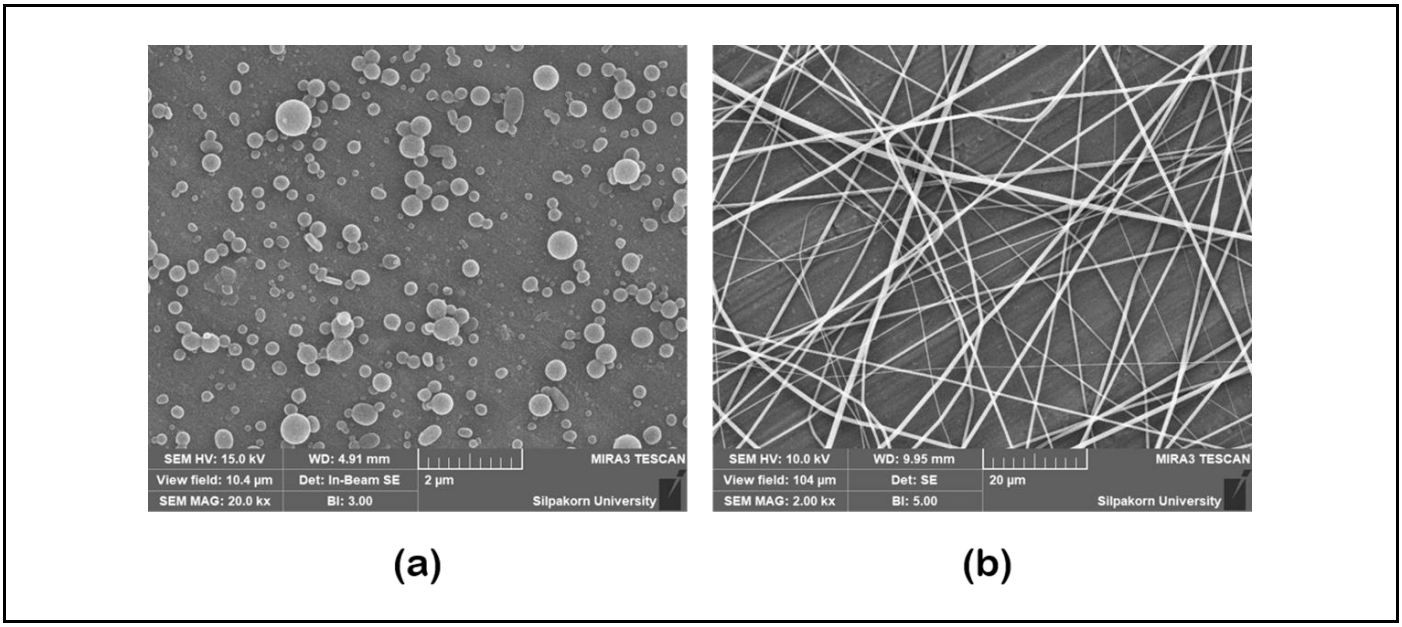

Figure 3. Shellac particles (a) and fibers (b) fabricated by electrospraying and electrospinning.

Table 1. Physicochemical properties and functionalities of native and modified shellac.

Modification category	Type of shellac	Physicochemical properties	Functionalities
	Native shellac	• pH-responsive solubility • Excellent film-forming ability • Acid resistance • Low water permeability • Thermoplastic behavior • Biodegradability • Biocompatibility	• Gastro-resistance • Moisture protection • Film formation • Controlled permeability • Sustained drug release
Chemical modification	Partially hydrolyzed shellac	• Increased carboxylic acid content • Enhanced ionization • Improved aqueous wettability	• Enhanced intestinal dissolution • Improved film elongation
	Salt-modified shellac	• Increased water dispersibility • Improved aqueous processability • Enhanced storage stability	• Rapid hydration under intestinal conditions • Enhanced intestinal dissolution
	Esterified shellac (shellac succinate/phthalate)	• Enhanced pH responsiveness • Improved storage stability • Increased intestinal solubility	• Enhanced intestinal dissolution while maintaining gastric resistance
Physical modification	Plasticized shellac	• Improved flexibility • Enhanced elasticity • Reduced brittleness	• Improved film integrity • Enhanced coating performance
	Thermally processed shellac	• Increased glass transition temperature • Reduced water uptake • Enhanced thermal stability	• Enhanced structural integrity • Enhanced moisture resistance
	Polymer-blended shellac	• Increased specific surface area • Reduced diffusion pathways	• Tailored release profiles • Expanded functionality for pharmaceutical and biomedical applications
	Shellac micro-/nanoparticles	• High surface area • Interconnected porous structure	• Improved drug release characteristics
	Electrospun shellac nanofibers		• Controlled drug delivery • Wound dressing applications

Overall, a variety of modification strategies have been developed to tailor the physicochemical properties of shellac through chemical, physical, and structural approaches as shown in Table 1. These modification strategies substantially expand the potential applications of shellac in pharmaceutical, biomedical, and advanced material fields. This versatility has greatly expanded the utility of shellac beyond its common role as an enteric coating polymer.

4. APPLICATIONS IN PHARMACEUTICAL AND BIOMEDICAL FIELDS

Shellac has long been used in a wide range of industrial applications, including wood finishing, packaging, edible coatings, printing inks, electrical insulation, and personal care products. Its excellent film-forming ability, acid resistance, low water permeability, surface gloss, and established safety profile have also supported its extensive use in pharmaceutical and biomedical applications, as discussed in the following sections.

4.1. Enteric drug delivery

Owing to its pH-responsive dissolution, film-forming capacity, and moisture-barrier properties, shellac has been widely used as an enteric and gastro-resistant coating material. Under gastric conditions, shellac coatings effectively retard gastric fluid penetration and suppress premature drug release. Dissolution generally begins as the environmental pH approaches approximately 7, enabling drug release in the distal small intestine or colon. However, because the pH of the proximal small intestine is often below this threshold, native shellac may dissolve too slowly to provide timely drug release in this region. To overcome this limitation, several modification strategies, including partial hydrolysis, salt formation, esterification with cyclic anhydrides, plasticization, and composite salt formation, have been developed to enhance shellac ionization and dissolution at intestinal pH while preserving its acid-resistant properties. These advances have broadened the application of shellac in modern enteric and site-specific drug delivery systems [5,8,15,16].

4.2. Colon-targeted drug delivery systems

Beyond its conventional use as an enteric coating material, shellac has been incorporated into a wide range of colon-targeted drug delivery systems, including tablets, capsules, pellets, anthocyanin–pectin beads, multiparticulate formulations, probiotic carriers, electrosprayed core–shell particles, electrospun nanofibers,

and hot-melt-extruded solid dispersions. Its limited solubility under gastric conditions and increased ionization at neutral to alkaline pH enable shellac to protect incorporated drugs during transit through the stomach and promote release in the distal intestine or colon. For example, shellac-based electrospun core–shell nanofibers have been developed to suppress drug release under acidic conditions and provide sustained release at neutral pH through gradual hydration, erosion, and dissolution of the shellac matrix. These findings demonstrate the potential of shellac as a functional polymer for advanced site-specific and colon-targeted drug delivery [17–21].

4.3. Floating drug delivery systems

Floating gastric drug delivery systems are designed to prolong the residence time of dosage forms in the stomach, thereby improving the bioavailability of drugs that are preferentially absorbed in the upper gastrointestinal tract or enhancing the effectiveness of locally acting gastric therapies. Owing to its acid-insoluble nature, shellac has been incorporated into effervescent floating matrix tablets to regulate the penetration of gastric fluid into the matrix and thereby retard drug diffusion. The addition of hydrophilic polymers, such as hydroxypropyl methylcellulose (HPMC), further promotes matrix swelling and gel formation. Consequently, these composite systems can maintain prolonged buoyancy while providing sustained drug release [22]. Similarly, shellac has been incorporated into floating pellets as a component of a swellable membrane layer that regulates the penetration of gastric fluid. When combined with other coating polymers, such as polyvinyl acetate (PVAc), shellac contributes to the formation of a mechanically stable membrane that preserves pellet integrity and buoyancy while enabling sustained drug release [23].

4.4. Micro- and nanoparticulate drug delivery systems

Shellac has been increasingly investigated as a carrier material for micro- and nanoparticulate drug delivery systems. These systems have been fabricated using several approaches, including electrospraying, ionic complexation with chitosan, and composite formation with zein, to improve encapsulation efficiency, physicochemical stability, and control of drug release. Electrospraying, in particular, has been successfully used to prepare shellac-based nanoparticles containing active compounds such as ferulic acid and tamoxifen citrate. Owing to the pH-responsive properties of shellac, these particulate systems can suppress drug release under acidic gastric conditions and promote enhanced release at intestinal pH [18,24]. Additionally, ionic complexation between shellac and chitosan has been used for fabricating nanoparticle carriers for controlled drug and protein delivery based on electrostatic interactions between oppositely charged polymers [25]. Composite formation between shellac and zein has been obviously reported to improve the encapsulation efficiency, physicochemical stability, and controlled release of bioactive compounds [26]. Recently, bicontinuous emulsions stabilized by zein–shellac composite nanoparticles have simultaneously enabled the incorporation of hydrophilic and lipophilic agents with high encapsulation efficiency [27].

4.5. Solid dispersion systems

Besides typical delivery systems, the hot-melt-extruded solid dispersion formulation consisting of shellac, HPMC and indomethacin has been effectively prepared with the purpose of colon-targeted delivery for poorly water-soluble drugs. The release of indomethacin was obviously reduced at gastric pH and was mostly completed at intestinal pH. Moreover, the dissolution of indomethacin was markedly elevated resulting from enhanced intermolecular hydrogen-bonding interactions between the components, thereby maintaining supersaturation [28].

4.6. Biomedical applications

In periodontal applications, bleached-shellac-based in situ systems incorporating antimicrobial agents such as doxycycline hyclate, metronidazole and benzyl peroxide have been explored with the capability of forming localized drug depots upon contact with aqueous environment, leading to sustained drug release and prolonged antimicrobial effect against oral pathogens [29]. Furthermore, the biocomposites of shellac, bovine hydroxyapatite (BHA) and *Agave cantula* fibers have been explored as potential dental materials for mimicking the properties of natural teeth with suitable physicochemical characteristics, hardness, and density [30]. Moreover, the combination of shellac and poly(lactic-co-glycolic acid) (PLGA) in melt-extruded preparations has been successfully applied in biodegradable implant systems with improved release of protein therapeutics and potential long-term controlled drug delivery [31].

Another biomedical application of shellac is wound dressings, especially in the form of electrospun nanofibers. Due to their advantageous features, including high surface area-to-volume ratio, interconnected porous structure, and extracellular matrix (ECM)-like characteristic, electrospun nanofibers promise a favorable condition for wound healing by enhancing oxygen permeation, maintaining a moist wound environment, and facilitating tissue regeneration. In addition, shellac-based nanofibers provide further

desirable properties, including excellent film-forming characteristics, biocompatibility, moisture-barrier properties, and compatibility with various therapeutic agents. To improve the therapeutic performance, antimicrobial compounds, such as monolaurin and nadifloxacin, are incorporated into electrospun shellac nanofibers. The obtained wound dressings exhibited sustained antimicrobial potential against common wound-associated microorganisms, while simultaneously performing a function as protective barriers with the prevention of microbial contamination [14,32]. Owing to its relatively low hydrophilicity, limited cell affinity, and moderate mechanical properties, shellac has been blended with hydrophilic polymers, such as gelatin, poly(N-isopropylacrylamide) (PNIPAm) and polyvinylpyrrolidone (PVP), with the aim of improving cell attachment, mechanical strength, and thermoresponsive behavior [12,32]. The shellac-based materials have become increasingly attractive for advanced wound dressing applications.

Apart from its application in wound dressings, shellac has been presently examined as a biodegradable component in bone tissue engineering for regenerative medicine. The combination of shellac and hydroxyapatite has been investigated to generate porous composite scaffolds, which imitate the mineral phase of natural bone. The obtained biocomposites exhibited favorable structural features, mechanical performance, and biodegradation behavior [33].

5. ADVANCED MANUFACTURING OF SHELLAC-BASED DRUG DELIVERY SYSTEMS

Three-dimensional (3D) printing has attracted considerable attention as an advanced manufacturing technology for the development of personalized oral dosage forms with customizable geometries and programmable drug-release profiles. Among the available techniques, fused deposition modeling (FDM) is particularly attractive because of its relatively low cost, solvent-free processing, and ability to fabricate dosage forms with complex and patient-specific structures.

Shellac has recently been investigated as a functional biopolymer for FDM-based pharmaceutical manufacturing. Owing to its thermoplastic behavior at relatively low processing temperatures, shellac can be combined with polyethylene glycol (PEG) as a plasticizer and processed by hot-melt extrusion (HME) to produce printable filaments, as illustrated in Figure 4. The resulting plasticized shellac filaments exhibit suitable mechanical strength, flexibility, and printability for FDM applications [34].

Using these filaments, two-piece drug delivery devices comprising a body and a cap have been successfully fabricated (Figure 5). Their mechanical properties, disintegration behavior, lag time, and drug-release profiles can be modulated by adjusting the wall thickness. In particular, increasing the wall thickness prolongs the lag time and delays drug release,

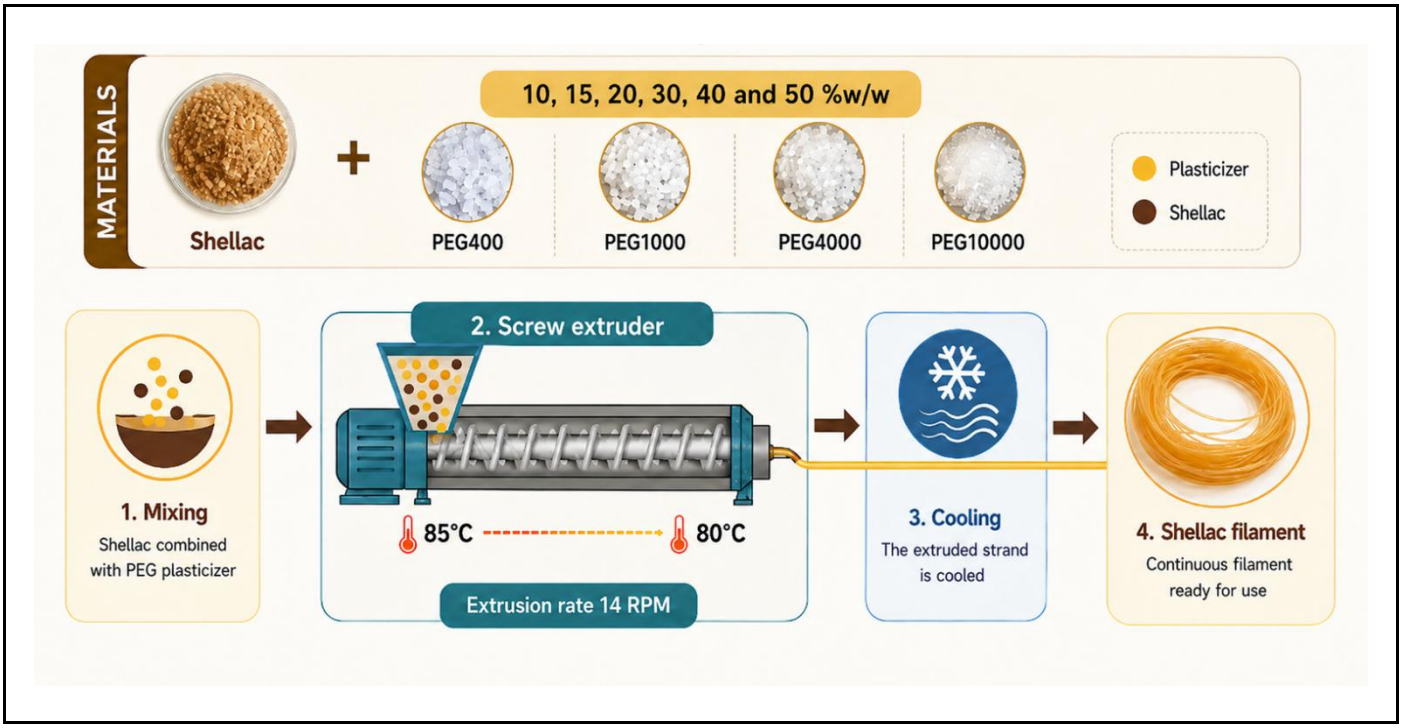

Figure 4. Schematic illustration of the fabrication of shellac-based filaments for fused deposition modeling (FDM) three-dimensional printing.

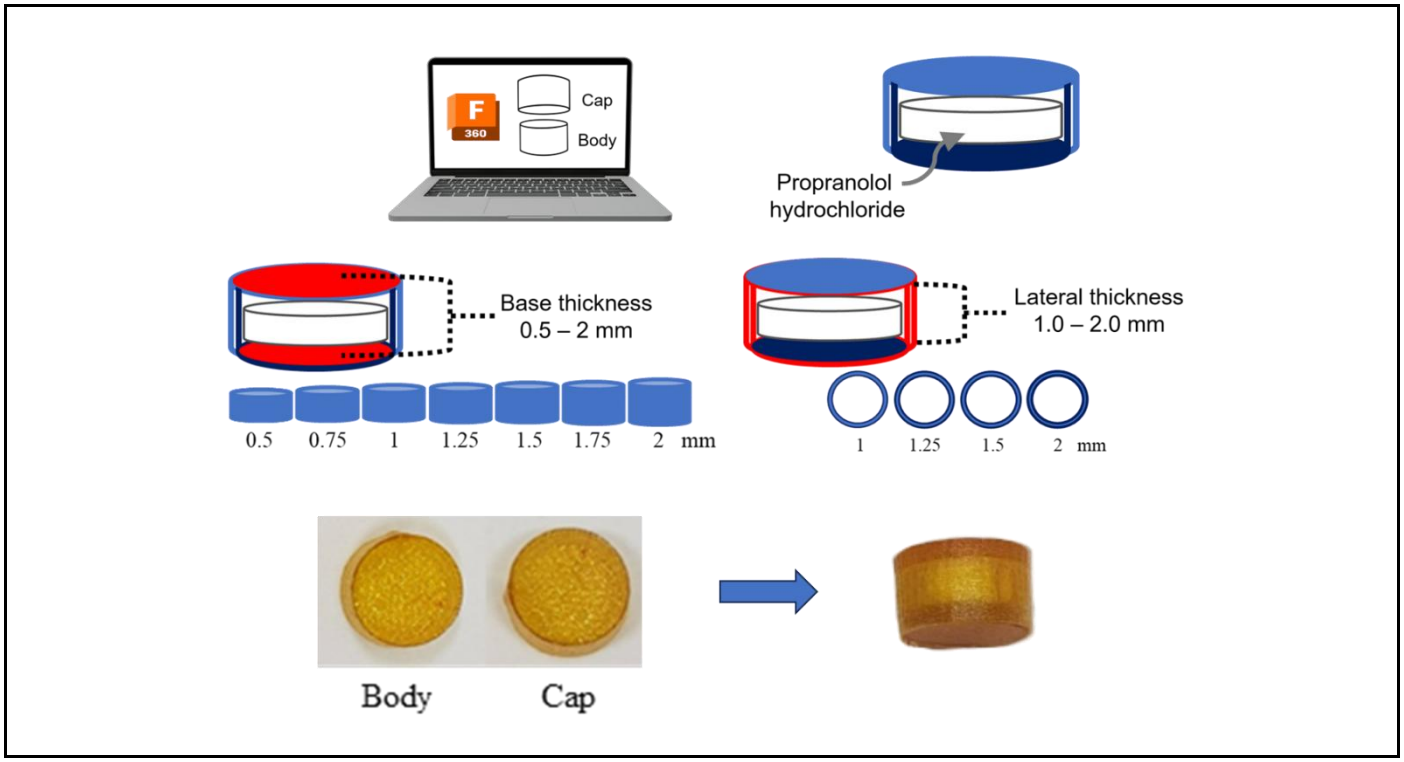

Figure 5. Schematic illustration of the fabrication of 3D printed shellac-based device for targeting drug to various parts of intestine.

thereby enabling release to be targeted to different regions of the gastrointestinal tract, from the upper intestine to the distal ileum or proximal colon. Importantly, the printed devices remain structurally intact under simulated gastric conditions, supporting their potential application in personalized and site-specific oral drug delivery [34].

Collectively, owing to its unique physicochemical properties, shellac has been extensively applied as a multifunctional biomaterial for advanced pharmaceutical manufacturing beyond its traditional role as an enteric coating material as shown in Table 2. The integration of shellac with functional biomaterials or advanced fabrication technologies has further enabled the improvement of multifunctional, personalized, site-specific and controlled drug delivery systems for precision medicine.

6. CONCLUSIONS

Shellac has been widely used for pharmaceutical and biomedical applications. Recent developments in modification approaches, formulation strategies, and manufacturing technologies have considerably extended its application in advanced drug delivery systems and biomedical applications. In order to accelerate the development of next-generation drug delivery systems, including flexibility in dosage form design, programmable drug release, and patient-specific therapies, the integration of shellac, a renewable natural polymer, with advanced fabrication technologies will play a substantial role in contributing to future innovations in pharmaceutical manufacturing and biomedical engineering.

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Author contributions

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Table 2. Pharmaceutical and biomedical applications of shellac.

Application	Systems	Advantages / Functionalities	References
Enteric and gastro-resistant drug delivery	• Enteric-coated tablets • Capsules • Pellets	• Gastric acid resistance • pH-responsive dissolution	(5,8,15,16)
Colon-targeted drug delivery systems	• Tablets • Capsules • Pellets • Anthocyanin–pectin beads • Multiparticulate systems • Probiotic carriers • Electrosprayed core–shell systems • Electrospun nanofibers • Hot-melt-extruded solid dispersions	• Site-specific drug delivery • Minimized gastric drug release • Sustained intestinal drug release	(17–21)
Gastroretentive drug delivery systems	• Floating matrix tablets • Floating pellets	• Prolonged gastric residence time • Sustained drug release • Improved bioavailability	(22,23)
Micro- and nanoparticulate drug delivery systems	• Electrosprayed nanoparticles • Chitosan–shellac nanoparticles • Zein–shellac nanoparticles • Bicontinuous emulsions	• Improved encapsulation efficiency • Controlled drug release • Enhanced physicochemical stability	(18,24–27)
Solid dispersion systems	• Hot-melt-extruded ternary solid dispersions	• Improved dissolution • Maintained supersaturation • Colon-targeted drug delivery	(28)
Periodontal drug delivery	• Bleached-shellac in situ systems	• Localized drug depot formation • Sustained antimicrobial activity	(29)
Dental materials	• BHA/shellac/Agave cantula biocomposites	• Favorable physicochemical properties • Suitable hardness and density	(30)
Biodegradable implant systems	• PLGA/shellac melt-extruded implants	• Long-term controlled drug delivery • Improved protein release	(31)
Wound dressings	• Electrospun shellac nanofibers • Polymer-blended nanofibers	• Moisture-barrier protection • Sustained antimicrobial activity • Tissue regeneration	(12,14,32)
Bone tissue engineering	• Hydroxyapatite/shellac porous scaffolds	• Favorable mechanical properties • Biodegradation • Bone regeneration potential	(33)
FDM-based three-dimensional printing	• Hot-melt-extruded shellac filaments • Two-piece oral dosage forms	• Personalized drug delivery • Site-specific drug release • Controlled drug release	(34)

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Declaration on the use of generative AI in scientific writing
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