Biopolymers for Medical Applications

Subjects: Polymer Science | Food Science & Technology

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Biopolymers are the organic substances present in natural sources. The term biopolymer originates from the Greek words bio and polymer, representing nature and living organisms. Large macromolecules made up of numerous repeating units are known as biopolymers. As per the IUPAC definition, a macromolecule defines a single molecule. The biopolymers are found to be biocompatible and biodegradable, making them useful in different applications, such as edible films, emulsions, packaging materials in the food industry, and as drug transport materials, medical implants like medical implants organs, wound healing, tissue scaffolds, and dressing materials in pharmaceutical industries.

biopolymers medical applications

1. Sources of Biopolymers

Plants, animals, microorganisms, and agricultural wastes are examples of natural biological sources of biopolymers. Plant sources, such as rice, maize [1], wheat [2], sorghum [3], yams [4], cassava [5], potatoes [6], banana [7], tapioca [8], corn [9], cotton [10], and barley [11] biopolymers can be produced chemically from monomeric components, such as oils, sugars, and amino acids. Cattles are the most common animal sources, while corals, sponges, fish, lobster, and shrimp are the most common marine sources. Algae, fungus, and yeasts are the most common microbiological sources (**Figure 1**). The origins and chemical structures of the main biopolymers are shown in **Table 1**. Agro leftovers, paper wastes, crops, green wastes, and wood wastes are carbohydrate-rich biomass-based sources. Triglycerides are found in vegetable oils, such as sunflower, soybean, safflower, jojoba, rapeseed, castor, and meadowfoam oil (**Figure 2**) [12]. Vegetable oils obtained from food producers, in particular, are excellent alternatives for natural polymer synthesis [13]. PHAs are a kind of biopolymer, secondary metabolites generated by microbes and plants. PHAs are stored as inclusion bodies in bacteria and are generated and aggregated intracellularly as transparent granules [14]. These biopolymers are produced naturally and degraded by microbial metabolisms, even though these biopolymers can be melted and shaped in the same way as the chemical and synthetic thermoplastics [15].

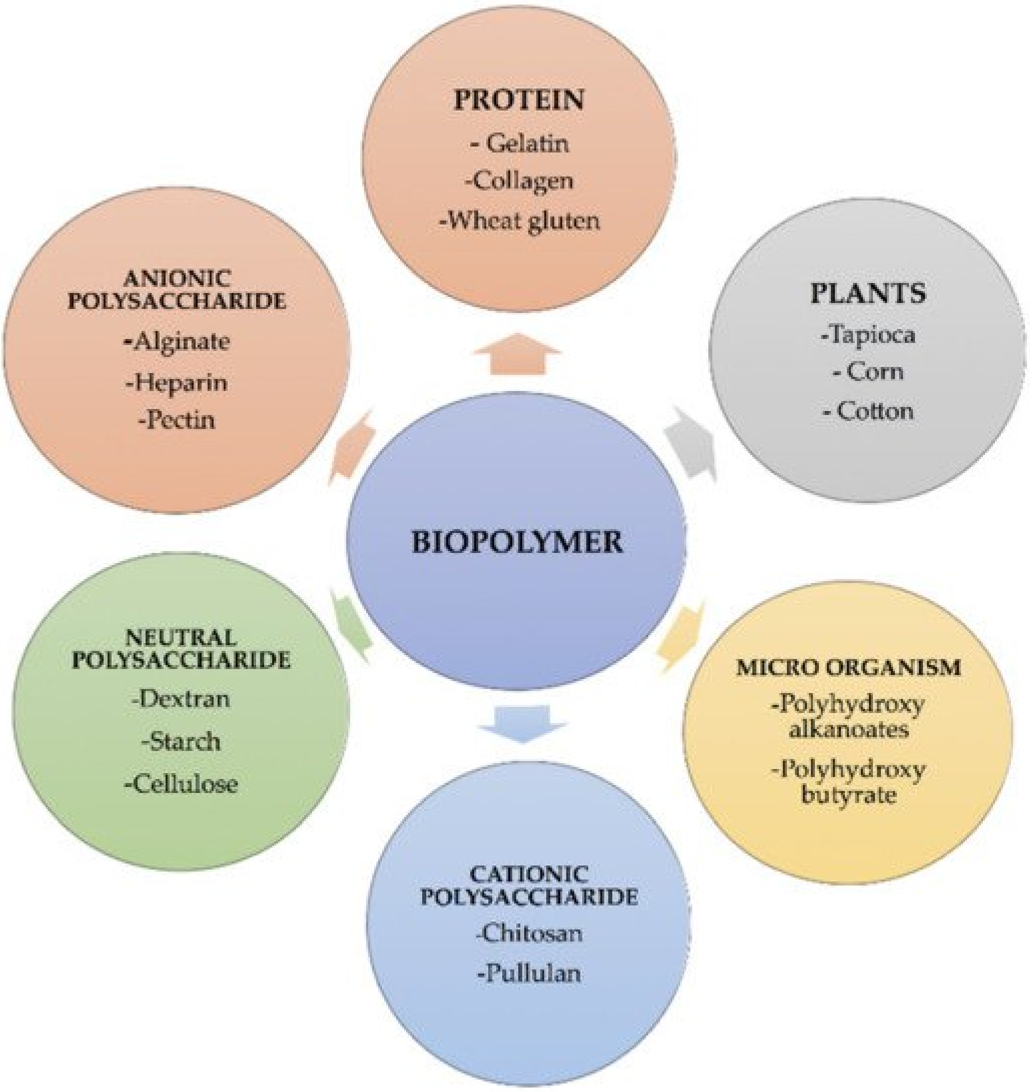


Figure 1. A pictorial depiction of several natural renewable biopolymers categorised according to their source.

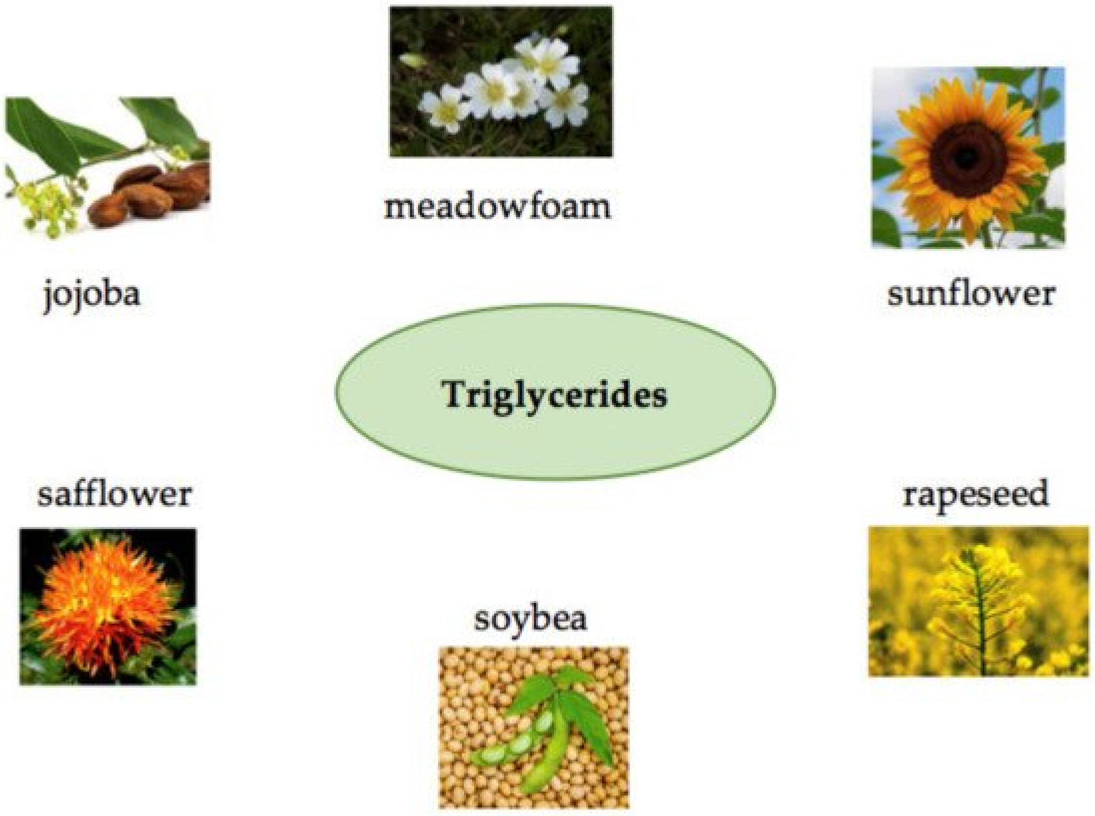
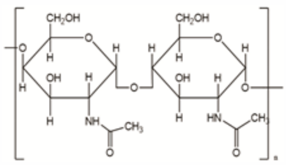
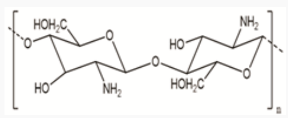
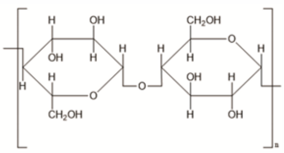
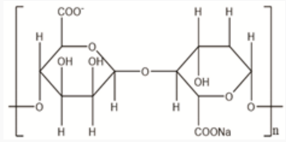
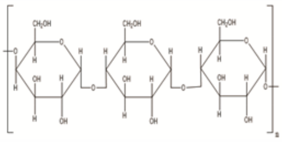
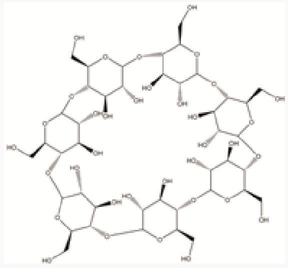
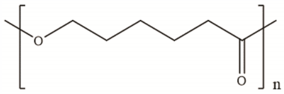


Figure 2. Tryglycerides in vegetable oils are an important source of biopolymers.

Table 1. Main biopolymers with their origins and chemical structures [16].

Biopolymers	Sources	Structure	Reference (Ref.)
Chitin	Corals, horseshoe worms, lamp shells, sponges, squid, cuttlefish, and clams are examples of aquatic species		[17][18]
Chitosan	Fungi, mollusks, algae, crustaceans, and insects		[17][19]
Cellulose	Agricultural trashes, such as Seaweed, rice husk, and sugarcane bagasse. Plant sources like wood, bamboo, sugarbeet, banana rachis, potato tubers, cotton, fique, kapok, agave, jute, kenaf, flax, hemp, vine, sisal, coconut, grass, wheat, rice, and barley		[20]

Biopolymers	Sources	Structure	Reference (Ref.)
Alginate	Seawood		[21]
Starch	Potatoes, maize, cassava, rice, sorghum, banana wheat, yams		[22]
Cyclodextrin	Starch sources like tapioca, potato, wheat, rice, and corn		[23]
Polycaprolactone	Polycondensation of ε -caprolactone		[24]

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2. Biopolymers for Medical Applications

Science and technology are essential factors in extending life expectancy. In this regard, various creative approaches and new equipment have been created, resulting in lower morbidity and death rates. The utilisation of drug delivery methods to increase the effectiveness of bioactive molecules is an essential technique for treating illnesses, and development in this area has been substantial. Synthetic, semi-synthetic, and natural polymers are commonly employed in the development of drug delivery systems in this context [25]. Suturing, fixing, adhesion, covering, occlusion, isolation, contact inhibition, cell proliferation, tissue guiding, and controlled drug administration [26][27][28][29] are just some of the medical applications that biopolymers could be used for. Several biomaterial production techniques and processes have been developed in recent decades to address and examine natural tissues' important functional architectural and compositional characteristics [30]. The hunt for better and more tissue-oriented implantable units has increased the understanding of biomaterials' potential and heightened interest in multimodal scaffolds with unique shapes and physical-chemical properties [31]. These scaffolds have multifunctional or multimodal qualities due to the integration of diverse topographies not generally present in each material, which boosts their potential relevance in regenerative medical techniques [32]. Polymers have a critical role in developing three-dimensional templates and the creation of synthetic extracellular matrix (ECM) habitats for tissue regeneration [33]. Biopolymers could be synthesised synthetically or from natural assets [34]. A range of composite materials and interpenetrating networks have been used to attain the required objectives since each group has specific benefits and limits. Due to the adaptability of synthetic polymers, which enables them to be

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adjusted to a broad range of degradation efficiency, structural traits, and mechanical characteristics, they are a reliable source of innovative materials. The synthetic polymer composition may be tailored to reduce immune response and combine the most significant features. Owing to its superior biodegradability and lack of cytotoxicity, natural polymers have been proposed as a viable alternative to commonly utilised synthetic materials. They are derived from natural sources, resemble soft tissues, and are formed through enzyme-catalysed chain-growth polymerisation processes of activated monomers, often created within cells during metabolic activities. Collagen, gelatine, dextran, agarose/alginate, hyaluronic acid, cellulose, and fibrin gels are all included in this category (**Table 2**). Despite being cleansed to prevent a foreign body reaction after implantation, natural polymers are commonly employed in regenerative medicine. Biodegradable polymers were chosen for the drug delivery system because they do not need surgery to remove once the medications have been released and may be excreted by the body. Some of the famous examples of biomedical applications that use biopolymers include soft-tissue replacement vascular grafts, breast implants, intraocular lenses, artificial hearts, components of extracorporeal oxygenators, contact lenses, plasmapheresis units, sutures, adhesives, and blood substitutes, dialyzers, liver, pancreas, bladder, kidney, bone cement, catheters, external and internal ear repairs, coatings for pharmaceutical tablets and capsules, cardiac assist devices, implantable pumps, pacemaker, encapsulations, heart valves, artificial blood vessels, joint replacements, artificial skin, dentistry, drug delivery and targeting sites of tumors or inflammation [35][36][37][38]. Since PHAs are biodegradable, they can be used as a substitute for petrochemical plastics in biomedical applications. The adaptability of poly (3-hydroxyoctanoate) in particular makes it a potentially appropriate choice as a biopolymer for drug delivery formulation as well as features of prospective tissue engineering [39].

Table 2. Examples of some biopolymers with their medical application.

Biopolymer	Medical Application	Ref.
Collagen	Surface coating for tissue culture plates Simple gels for cell culture	[40]
Alginate	Regenerative medicine Tissue engineering	[41]
Hyaluronic acid	Treatment and lubrication of damaged joints Cutaneous and corneal wound healing	[42]
Fibrin	Blood clotting, wound healing, and tumor growth Hemostatic agent, sealant, and surgical glue Regenerative medicine	[43]
Silk fibroin	Treatment of wounds, bioengineering of tissues	[44]

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Biopolymer	Medical Application	Ref.
Agarose	Skeletal tissues regeneration, kidney and fibroblast encapsulation	[45]
Carrageenan	Skeletal tissues regeneration, cell delivery system	[46]
Fibronectin	Wound healing, cardiac repair, bone regeneration	[47]
PHAs	Drug delivery systems, bone tissue regeneration,	[48]
Elastin	soft-tissue reconstruction, orthopedics and cell encapsulation	[49]
Keratin	Cornea tissue engineering, skin regeneration	[50]
Starch	Bone and cartilage regeneration, spinal cord injury treatment	[51]

Many natural biomaterials based on biopolymers have been studied for hard and soft-tissue repair. They can be utilised independently or with other synthetic or inorganic components. The specific dressing, nursing care, and decreased grafting time are the key features of these tissue-engineered materials. Many recent in vivo studies contributed to the FDA clearance of innovative biomaterials for clinical use based on natural biopolymers as matrices for cell distribution and scaffolds for cell-free support of native tissues, despite their mechanical fragility and high cost. For cell encapsulation, a variety of naturally occurring and manufactured biopolymers that might be synthesised into diverse physical forms and geometries are used. The biomaterial component of these therapies must offer suitable mass transport characteristics, membranes, or scaffold stability, and acceptable cellular interactions depending on the site and intended function of the implant. Intelligent biopolymer hydrogels that vary their swelling behaviour and other features in response to chemical and physical stimuli, including pH, metabolites or/and ionic variables, temperature, and electric fields, have piqued curiosity. These “smart” hydrogels exhibit single or multiple stimuli-responsive properties. They may be used in a variety of biomedical applications, varying from cell adhesion mediators and controlled drug delivery systems to controllers of gene expression and enzyme function in bioengineering or tissue engineering, in addition to their biocompatibility, biodegradability, and biological processes. Biopolymers may be readily functionalized to improve cell interactions and provide an appropriate platform for cellular and tissue functions. There are two types of peptide-based biopolymers in tissue engineering: self-assembling polypeptides that form gels in response to environmental cues, and polypeptides that create gels by chemical cross-linking. The biopolymer blocks' unique bioactivity, biocompatibility, and biodegradability properties enable it to be used in various biomedical applications [52]. Polymer–biopolymer interactions are becoming more and more capable of being planned and selected, allowing for their intervention in cellular dysfunctions and developing more effective, targeted, and efficacious therapeutics. Due to the degree of control possible via live polymerisation techniques, previously available structure-function connections for bio-

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macromolecules, may now be integrated for fully synthetic materials. Simultaneously, the production and activity of biopolymers may be controlled using molecular biology techniques. Because the ability to control the structure of polymers results in the power to modify their functioning, this synthesis of natural and synthetic macromolecular chemistry inevitably results in biomedical applications. A few examples of the medical application of biopolymers have been presented in **Table 2**. Bio-printers can automate the assembly process and allow for complex biopolymer manipulation—from the macromolecular to the living cell level—to achieve architectural and biochemical complexity never before possible, resulting in tissue and organ substitutes that closely resemble their natural counterparts. These many regenerative medicine approaches are likely to transition from 'bench to bedside' in the future.

The potential of biodegradable nanoparticles has been explored by various researchers for a wide range of biomedical applications due to their properties, such as biocompatibility and bio-safety. Depending on their size, nature, and design, various nanoparticles have distinct therapeutic efficacy, bioavailability, and delivery components. Nanotechnology-assisted imaging is advantageous not only in the field of cancer but also in the field of cardiovascular disease [53][54]. Micelles are helpful in cancer treatment by focusing on malignant cells using tumor molecular probes [55].

2.1. Biomedical Applications of Protein-Based Biopolymers

Protein-based biopolymers play a vital role in medical applications. Biopolymers have biocompatible, non-toxic, and biodegradable properties. Their application to implantable devices is expanding rapidly and has great potential [56]. As the molecular sizes of proteins are governed by their secondary structures, the production of nanoparticles proteins permits the formation of precisely constructed nanoparticles [57].

Regenerative tissue engineering aims to use the body's inherent healing potential to improve injured or damaged tissue function. Synthetic polymers and biopolymers are used as scaffolding to establish a favorable environment for cell proliferation and tissue repair. Collagen, keratin, gelatine, sericin, and fibroin are used to make films, pickering emulsions, hydrogels, nanogels, nanofibers, linked porous scaffolds, and 3D-printed scaffolds [29][58][59][60][61][62][63]. Tissue engineering and therapeutics molecules (gene delivery, drug delivery, protein delivery) are delivered via collagen-based nanospheres, nanoparticles, sponges, electrospun fiber, and hydrogel [64].

Gelatin is a non-toxic, biodegradable, and FDA-approved substance. Acid (type A gelatine) or essential (type B gelatine) hydrolysis is used to extract from bovine or porcine sources. Gelatine has been extracted from a variety of sources, including jellyfish, fins, bones, and sea urchins [65]. Gel formation, thickening, emulsification, and foaming are characteristics of gelatine [66].

2.2. Chitosan in Medical Applications

Chitosan is also widely used in medical uses because of its biodegradable and biocompatible properties. It has a variety of uses (gels, films, particles, membranes, or scaffolding, etc.) from biomedical to industrial fields. In addition, due to its properties, chitosan plays an essential role in cell attachment and growth. It is widely used as a

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tissue engineering matrix when manufactured in a porous structure. The main uses of chitosan in implants are bone, ligament, cartilage, tendon, liver, neural, stem, and skin regeneration. Several examples of chitosan-based matrices for bone applications have been reported. However, due to its mechanical weakness [67], there is a need to combine chitosan with other materials in applications for bone tissue engineering [68]. Nanoparticles formed using chitosan display interesting properties, such as low toxicity; good absorbability, permeability, and moisture retention; and is easily degradable. However, they suffer from poor long-term stability and are very sensitive to environmental temperature and pH, which affects the degradation rate [69].

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