Biodegradable Polymers and their Classification: A Brief Review

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Abstract: Since the declining reservoir of fossil fuels and the ever-increasing concern for the environment, there has been a surge of interest in bio-based and biodegradable goods over the last few decades. Agro-polymers (such as starch, chitin, protein, and so on) and biodegradable polyesters [polyhydroxyalkanoates, poly (lactic acid), and so on] are the two major types of biodegradable polymers. The above, also known as bio-polyesters, can be synthesized from fossil fuels, but the majority of output comes from renewable resources. This review will discuss the synthesis, structure, properties, and applications of this particular class of polymers.

Keywords: biodegradable polymers; biodegradable; sustainable; polylactides

1. Introduction

1.1. Relevance of Biodegradable Polymers

Polymers have risen to prominence in contemporary materials science for a variety of reasons. The evolution of the inflatable rubber tyre in the modern transportation world would not have been possible without the use of natural, and later synthetic, rubbers as energy-absorbing materials. Because of their superior physical properties, especially strength and durability, lightness, and barrier properties, plastics have replaced a large portion of conventional packaging materials. Their ability to protect fragile goods (perishable) against spoilage at a low cost has resulted in a revolution in food distribution, to the point that they are now indispensable in modern retailing.[1]

Synthetic polymers are regarded as a priceless contribution of scientific science and technology to humanity. They have been indispensable in our lives due to their vast variety of applications in fields as varied as packaging, agriculture, food, consumer goods, medical equipment, construction materials, industry, aerospace materials, and so on. Synthetic polymers, on the other hand, are considered to be resistant to chemical, physical, and biological deterioration. When used in fields such as surgery, pharmacology, agriculture and the environment, this has become a major problem,

and as a result, time tolerant polymeric wastes are becoming less and less suitable by the day.[2]

As an alternative to current polymers, the need for polymeric materials that can meet the requirements of biodegradability, biocompatibility and releases low-toxicity degradation products is apparent.[3]

The extreme environmental issues, along with the growing challenges of waste management and the looming danger of global warming caused by CO_2 emitted during incineration as a result of the non-degradability of many polymers, such as polyethylene, have sparked worldwide concern.

As concerned people, we must challenge them in order to create a modern world and a thriving community free of plastic waste in the twenty-first century. This is why the use of biodegradable counterparts as an alternative to non-degradable polymers is gaining popularity recently. The unfortunate aspect is that the degradable polymers available until recently had poor physical properties in terms of strength and dimensional stability, with the majority of them being prohibitively costly to produce. As a result, efforts are being made to address the challenges by incorporating biodegradability into polymers used in daily life by correctly changing their shape.[4]

From an environmental standpoint, degradability is not the only issue to be concerned with. Polymer applications in medicine are at an all-time peak right now. Biodegradable polymers derived from
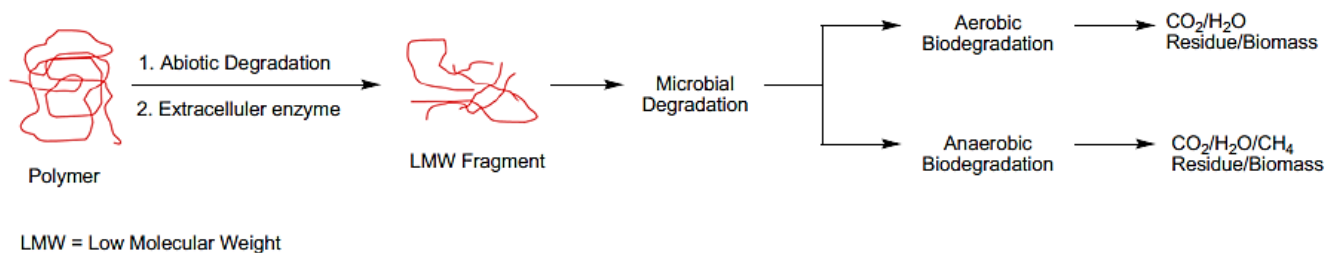
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Chem. Sci. Eng. Res., 2022, 4(9), 19-28.

19

Fig. 1. Chemistry of biodegradation.

renewable materials have attracted a lot of attention in recent years because they have many attractive properties such as biocompatibility, biodegradability, and natural abundance. Recently, a variety of biodegradable polymers of natural and synthetic origin with strong biodegradability and biocompatibility has emerged. They do, however, have certain underlying issues that necessitate debate and the development of science and technical solutions. The current thesis proposes to address the unresolved properties of biodegradable polymers, with a focus on the issues and possibilities of (1) methods used to turn non-biodegradable polymers and synthetic polymers into biodegradable polymers, and (2) biodegradable polymers and copolymers derived from natural sources such as lactic acid. Polylactide/polyglycolide polymers are now the most commonly used synthetic biodegradable polymers for biomedical applications. However, certain shortcomings of Poly(lactic acid) (PLA), such as low hydrophilicity and degradation rate, weak soft tissue compatibility, low thermal and physical properties, lack of processing technology, high manufacturing costs, and its expanded application in medicine, necessitate the quest for newer materials with unique properties for particular applicability in the sector.[5-6] After the success of the first synthetic poly (glycolic acid) (PGA), the field of synthetic biodegradable polymers has grown into several groups, with poly(hydroxyalkanoate) and aliphatic polyesters being the two main classes.[7]

1.2. Definition

Biodegradation is a degradation process caused or propagated by microorganisms such as bacteria and fungi. To be rendered biodegradable, polymeric fractions must be assimilated by microorganisms and fully mineralized into carbon dioxide, water, and biomass. The concept of polymer biodegradation varies depending on the application. Biodegradation was described by Albertson and Karlsson as 'an event that takes place through the action of enzymes and/or chemical decomposition associated with living organisms and their secretion products'.[8] Abiotic reactions such as photo-degradation, oxidation, and hydrolysis must also be addressed since they can alter the polymer prior to or during biodegradation due to environmental concerns. Thus, strictly speaking, polymer biodegradation is better characterized as the deterioration of its physical and chemical properties, as well as a decrease in molecular mass, caused by the formation of CO_2, H_2O, CH_4, and other low molecular-weight products under the control of microorganisms in both aerobic and anaerobic environments, assisted by abiotic chemical reactions such as photo-degradation, oxidation, and hydrolysis.[9]

Biodegradable polymers (plastics) are described by ASTM D 6400-99 as degradable plastics that degrade due to the activity of naturally occurring microorganisms such as bacteria, fungi, and algae. According to the ISO concept of biodegradable polymers, all that is needed is a chemical shift in the substance caused by microorganisms. The DIN norm, on the other hand, requires polymer conversion into microbial metabolic products. However, the most general concept is biodegradable polymers are polymers that degrade to compostable materials under normal environmental conditions (both aerobic and anaerobic) within a reasonable time after their useful life. Environmentally appropriate degradable polymers are characterized as polymers that degrade in the environment through a variety of mechanisms, resulting in complete biodegradation that leaves no detectable residue in the environment.[10-14]

1.3. Chemistry of Bio-degradation

The only degradation pathway that can fully eliminate a polymer or its degradation products from the environment is biodegradation. Biodegradation occurs in two steps (Fig. 1). Depolymerization of macromolecules into shorter chains is the first step that happens outside the organism. The process involved in the second step is mineralization. Once enough short chain polymeric fragments have been formed, they are transferred into cells, where they are bio assimilated by microbes and then mineralized. Biodegradation occurs under two distinct environments based on the availability of oxygen: aerobic when oxygen is present and anaerobic when oxygen is not present. If no trace exists after biodegradation, the process is said to be complete.[15]

1.4. Methods of Bio-degradation

The breakdown of polymeric materials is thought to occur through microbial activity, photodegradation, or chemical degradation. Since the final products are durable and found in nature, both of these processes are considered biodegradation. Biopolymers are designed to be discarded in landfills, composts, or dirt. If the required microorganisms are present in the dumping area, the polymeric materials will degrade. Normally, only soil bacteria and water are needed for degradative processes. When starch is used as an additive to a traditional plastic matrix, the polymer that comes into contact with the soil and/or water is targeted by the microbes present.

The starch is digested by the microbe, leaving behind a porous, sponge-like structure with a large interfacial region but poor structural strength. Where the starch portion is reduced or missing,

Chem. Sci. Eng. Res., 2022, 4(9), 19-28.

20

an enzymatic attack starts to degrade the polymer matrix. The weight of the matrix is decreased after each reaction due to natural scission, and this process continues until all of the material has been digested.[7]

Another path to microbial degradation of biopolymers may be to culture microorganisms specifically for the purpose of digesting polymer materials. This method, on the other hand, is more intensive, more expensive, and prevents the use of renewable resources as biopolymer feedstock. The microorganisms are specifically engineered to attack and degrade petroleum based plastics.[16]

Photodegradable polymers decay and break down into smaller fragments when exposed to sunlight. True biodegradation requires microbial degradation. Polyolefin have been shown to be the most vulnerable to photo-degradation.[17]

Procter and Gamble has created a polymer called Nodax PBHB, which is alkaline digestible, which means that it breaks down quickly when exposed to a solvent with a high pH.

Biopolymers that degrade when exposed to aqueous solutions are preferable for the disposal and transportation of biohazardous products and medical waste.[18]

Degradation is visible at the macroscopic level as modifications and decay of core material properties such as cranking, breakage, fragmentation, and so on. These modifications are the result of the shortening of polymer chains, which define the majority of the polymer's properties.

The concentration of functional groups formed during degradation can be used to detect changes at the molecular level. The amount of carbonyl groups ($>C=O$) produced by the oxidative process is generally determined using IR spectroscopy. However, the presence of carbonyl groups does not mean polymer chain scission, which has a significant impact on the mechanical properties of the polymer. The distribution of molar masses of the polymer is used to specifically analyze chain scission. Molar masses can be calculated by calculating melt or solution viscosity, size-exclusion chromatography, or, for lower molar masses, mass spectroscopy. This gives us about the statistical distribution of molar masses, or the average molar mass (average length of the polymer chain), as well as the width of the distribution, which indicates the size of chain lengths. Mechanical properties such as tensile strength, hardness, and flexural strength are lost when the polymer chain is shortened.[19]

Decomposition typically starts with fragmentation, which occurs when a substance is exposed to living (enzymes, organisms) or non-living factors (e.g., UV light, fire, water) that causes a chemical decomposition of the polymer and thus mechanical decomposition. In the next phase, microorganisms mineralize the results of this decomposition. The partly degraded polymers (fragments) are metabolized into end products during this second period, which defines the process as biodegradation. The mineralization level determines the final stage of biodegradation.

Since organic carbon is oxidized to CO_2 during the aerobic oxidation period, the most common method of tracking this stage is to measure the amount of CO_2 produced in a closed environment (humidity, temperature, pH, absence of toxic substances) for the presence of the microorganism community.[19-20]

Polymers can be chemically degraded by a variety of microorganisms. They vary significantly in that they are active under very different conditions (humidity, pH, temperature, salinity, and so on) and thus more or less adapted for decomposing different substrates based on the enzymatic systems they use. These requirements largely determine whether they will decompose. An example of such specialization by a microorganism can be seen in the fungus Phanerochaete chyrsosporium and other white-rot fungi, which decompose lignin in natural environments using oxidases that catalyze oxidation.[21]

1.5. Biodegradation time-scale

Under the effect of the atmosphere and microorganisms, every organic substance, including ordinary plastics, degrades mechanically and chemically. However, the degradation process could take a long time. This is important not only in terms of use, but also in terms of the environmental effects of decomposition materials (e.g. fragments). Compostable plastics are an example of a material whose biodegradation rate is essential but severely restricted. If plastic fragments and the resultant contaminants cannot be mineralized, the compost will contain small particles of artificial compounds with uncertain long-term effects on normal living and non-living conditions. This poses a danger because the particles, once scattered in nature, are difficult to collect and can remain in nature for an extended period of time. Compostable plastics, on the other hand, will fracture during the composting stage, and the mineralization process will begin within the specified time frame for bio-waste degradation (e.g. grass, household waste).[17]

1.6. Materials

A polymer's susceptibility to degradation is solely determined by its chemical composition. As a result, whether the polymer is made from renewable or non-renewable materials has no bearing on biodegradability. What is essential is the final configuration. As a result, biodegradable polymers may be either renewable or non-renewable.[22]

A widespread misconception is that all biodegradable polymers are derived from renewable materials. Different procedures for producing biodegradable polymers may be used without compromising the material's biodegradability. Synthetic (chemical) or bio-technological (affected by microorganisms or enzymes) methods may be used. The below are the most widely used procedures:[19]

- Making plastics from natural polymers that have been manually or chemically refined (e.g. plastics based on destructured starch)
- Creating a polymer chemically from a monomer derived from bio-technological conversion of a natural resource (e.g. use of lactic acid produced from the fermentation of sugars for the production of PLA). In these situations, the polymer is produced chemically from a natural material.
- Synthesis of a polymer using a biotechnological technique based on a renewable resource (e.g. fermentation of sugars where natural microorganisms synthesizes thermoplastic aliphatic polyesters, such as polyhydroxybutyrate- PHB).

- Chemical synthesis of a polymer based on components derived from non-renewable materials using a petrochemical process.

A variety of industrial biodegradable plastics are now available on the market from a variety of manufacturers. These traditional materials are classified as follows:[23]

- Plastics derived from starch
- Plastics based on polylactides (PLA)
- Plastics based on polyhydroxyalkanoates (PHB, PHBV, etc.)
- Plastics based on aliphatic-aromatic polyesters
- Plastics derived from cellulose (cellophane, etc.)
- Plastics derived from lignin.

2. Classification

Biodegradable polymers can be divided into two broad categories depending on their composition and synthesis. Agro-polymers, or those extracted from biomass, are one of these classes. The other form is biopolyesters, which can be extracted from microorganisms or synthesized from natural or synthetic monomers. Polysaccharides, such as starches found in potatoes or wood, and proteins, such as animal-derived whey or plant-derived gluten, are examples of agro polymers. Polysaccharides are made up of bonds that take a hemiacetal of a saccharide and bind it to an alcohol through water loss. Proteins are made up of amino acids, which have a variety of functional groups. These amino acids recombine to form peptide bonds, which contain amide functional groups, through condensation reactions. PHB and PLA are two examples of biopolyesters (Fig. 2).[24]

Various biodegradable polymer classifications have been proposed. The biodegradable polymers in this case are categorized based on the processes used in their synthesis.[25]

1. Polymers derived from biomass, such as agro-polymers (e.g., starch or cellulose),
2. Polymers derived from microbial fermentation, such as polyhydroxyalkanoates (PHAs)
3. Polymers derived from agro-resources, such as PLA and
4. Polymers derived from fossil resources.

The diagram below depicts the classification of biodegradable polymers based on composition and occurrence.

In the 1980s, researchers started looking for biodegradable polymers made from natural materials. It has been enthusiastically adopted by the 'green' movement, which has influenced the science community and, as a result, the polymer production industry itself. The listed goals of this quest are as follows:[26]

- To be used in place of polyolefin (PO) and polyvinyl chlorides (PVC), regardless of the properties desired.
- To match the costs of processing of PO and PVC.
- To limit the total 'metabolic burning time' in a technical composting device to two composting periods (30 days).

The polymer companies have now adopted the 'renewable definition'. While discovered in 1925, the first completely biosynthetic/biodegradable polymer, PHB, was developed on a semi technical scale by ICI in the 1980s by microbial sugar fermentation.
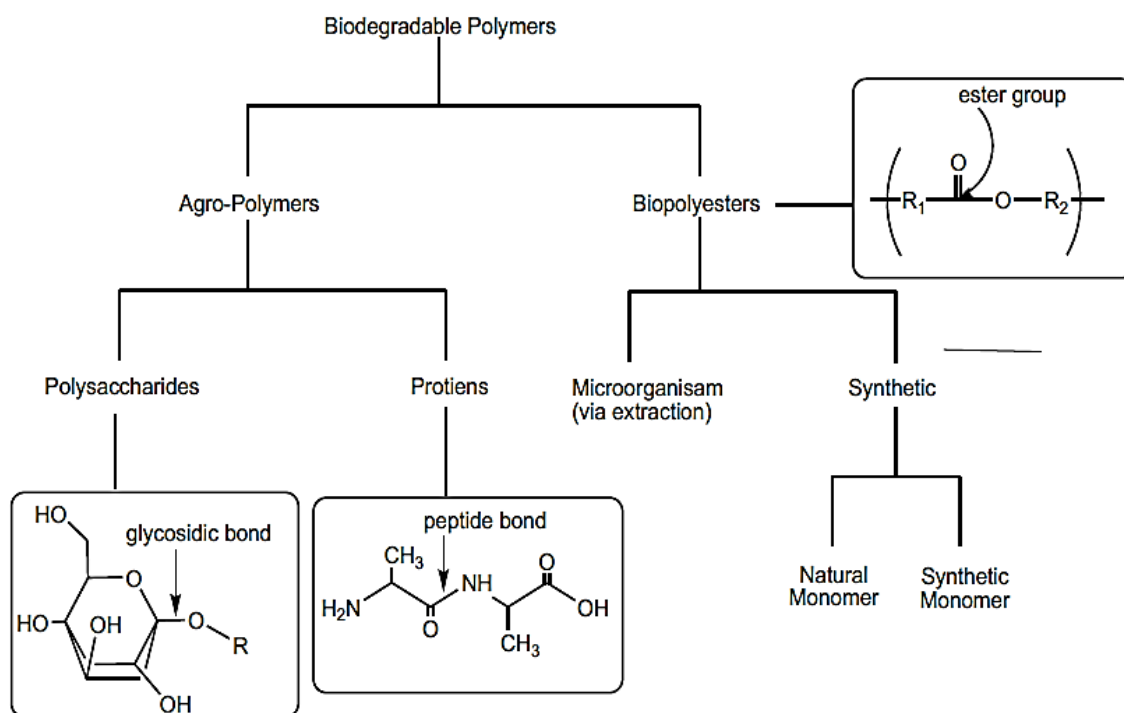

Fig. 2. Biodegradable polymers organization based on structure and occurrence.[24]

The discovery of this and similar polyesters, the PHAs, sparked a hunt for other bio-based biodegradable polymers. PLA, a hydro-biodegradable polymer synthesized from com sugar using traditional abiotic chemistry, is manufactured on a modest commercial scale. PLA's mechanical nature is said to be close to that of polyethylene, based on extensive research into its properties.[27]

In its natural state, starch has little importance in the plastics industry. It can, however, be turned into a plastic by extrusion cooking that, when plasticized, approaches the properties of commodity plastics. The rationale for using starch as a base material for plastics is that it degrades quickly in water. Corn starch is a relatively inexpensive material, but being green and inexpensive does not inherently imply that it is affordable, and if the conditions of the above prototype are to be met, agricultural production of starch for the plastics industry competes with food production.[28]

Nature's cellulose-based debris abounds both on land and at sea. The majority of this happens in conjunction with lignin, and in theory, these plentiful materials should be used to build a truly sustainable polymer industry.[29]

Let us now turn our attention to a more in-depth overview of the different groups of biodegradable polymers. We'll use concrete examples to talk about the different facets of the polymer of concern. We begin with agro-based biodegradable polymers, then move on to biopolyesters.[22]

2.1. Agro-polymers

Polysaccharides and proteins are the key agro-polymers discussed in this article. These are often used in the preparation of multiphase products.[24]

2.1.1. Polysaccharides

Polysaccharides are the biosphere's most common macromolecules. These complex carbohydrates, which are made up of glycosidic bonds, are often the major structural components of the exoskeletons of plants and animals (cellulose, carrageenan, chitin etc.). Starch, chitin, chitosan, and pectin are the polysaccharides discussed in this work/paper in order.[30]

2.1.1.1. Starch

Starch is mostly derived from cereals (wheat, corn, rice, and so on) and tubers (potatoes, manioc etc.). It is stored in the form of seeds or roots and serves as the primary plant energy reserve.[31]

Native Starch Structure:

Starch granules can vary in shape (sphere, platelet, and polygon) and size depending on the plant's origin. The amylose and amylopectin - D-glucopyranosehomopolymers make up these granules.

Amylose is a linear polysaccharide consisting primarily of D-glucose units connected by (1→4) linkages. These chains are partly ramified by a(1→6) linkages. The molecular weight of amylose ranges from 105 to 106 g/mol^{-1} depending on the source and the extraction method, with a polydispersity varying from 1.3 to 2.1. The amylose chains have a single or double-helical structure with a rotation on the (1→4) linkages.[32-34]
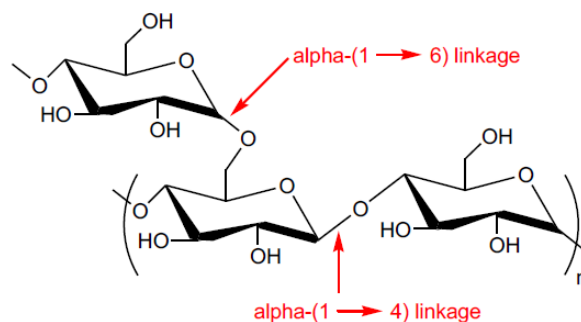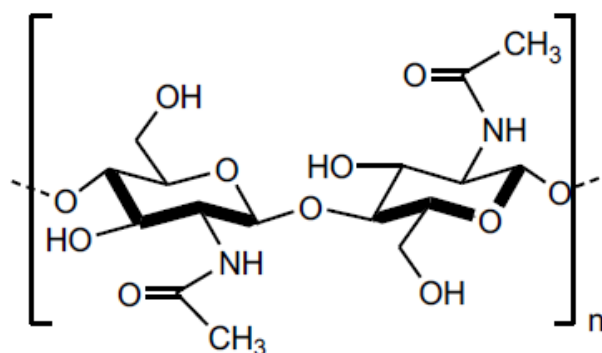

Fig. 3. Chemical structure of Amylopectin.[34]

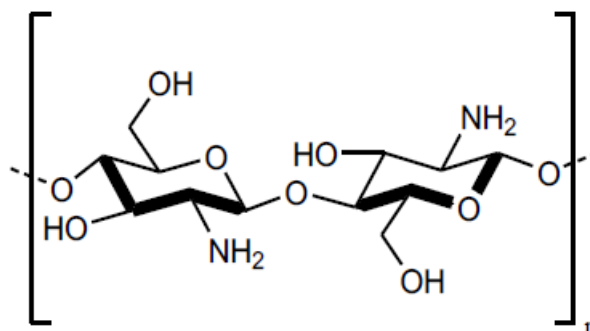**Fig. 4.** Structure of Chitin.

Fig. 5. Structure of Chitosan.

Amylopectin, the main ingredient of starch, has the same monomeric unit as amylose. It reveals 95% (1→4) linkages and 5% (1→6) linkages(Fig. 3). These latter are located every 24–79 glucose units and provide a strongly branched structure to amylopectin. The arrangement of starch granules consists of alternate crystalline and amorphous areas that contribute to a concentric pattern. The crystalline components are also made up of amylopectin side chains. Any co-crystalline structures containing amylose chains have also been discovered. There are four allomorphic starch systems. The crystallinity of starch granules varies from 20-45% depending on the botanical roots.[35]
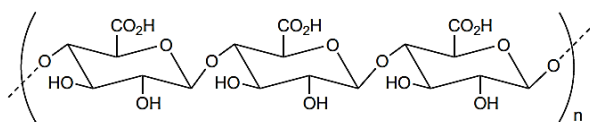
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Chem. Sci. Eng. Res., 2022, 4(9), 19-28.

23

Fig. 6. Structure of Pectin.
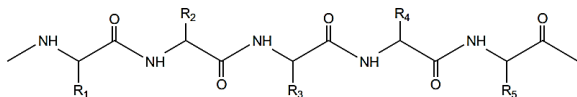

Fig. 7. Chemical structure of protein.

Fig. 8. The chemical structure of PLA.

2.1.1.2. Chitin and Chitosan

After cellulose, chitin is the most abundant biodegradable biopolymer. Chitin is derived mostly from the exoskeletons of various arthropods and the cell walls of some fungi. It is a linear N-acetyl glucosamine homopolymer with (1→4) linkages that exhibits cationic activity (Fig. 4). Chitin has a low solubility profile and hence needs further consideration for further development. Chitosan is thought to be the most refined form of chitin. This white to light red powdery material is more soluble than chitin. While chitosan is insoluble in water, it is soluble in a wide range of organic acids, including formic acid, acetic acid, tartaric acid, and others. It is also one of the most adaptable, one-of-a-kind, and multi-functional biopolymers with intrinsic biological properties. Chitosan is a linear polysaccharide with randomly distributed D-glucosamine and Nacetyl-D-glucosamine - 1,4-linkages (Fig. 5).[36]

2.1.1.3. Pectin

Pectin is a linear macromolecule made up of α-(1→4)-linked D-galacturonic acid (Fig. 6). This monomer unit could be partly replaced by α-(1→2)-linked L-rhamnose, resulting in rhamnogalacturonan I. About 80% of the galacturonic acid carboxyl groups are naturally esterified with methanol. Pectins are categorized as high- or low-ester pectins based on their behavior in food applications. Non-esterified galacturonic acid units may be free acid or salts, with sodium, potassium, or calcium acting as the counter ion. Pectinates are partially esterified pectin salts. If the degree of esterification is less than 5%, the salts are referred to as pectates.[38]

2.2. Polyamides

Proteins are a form of agropolymer. A number of proteins have gained significant interest as biodegradable polymers, but only a handful has resulted in real commercial scale-up due to high manufacturing costs and poor product efficiency. Soy proteins, corn proteins, and wheat proteins are the other plant proteins that may be used as protein sources. Similarly, lactate dehydrogenase, chymotrypsin and fumarase constitute the main bacterial proteins. Similarly, the major bacterial proteins are lactate dehydrogenase, chymotrypsin, and fumarase. Most proteins are made up of linear polymers made up of up to 20 different amino acids (Fig.7). Regular amino acid side chains have a wide range of chemical configurations and properties. The cumulative influence of both of the amino acid
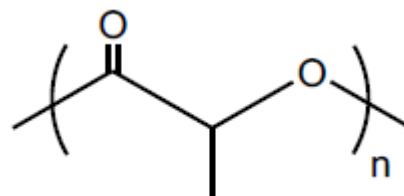
side chains determines the final 3D structure and chemical reactivity. Biochemists distinguish four distinct protein structures:[38]

- Primary structure: The chain of amino acids (Fig. 7)
- Secondary structure: H-bonds stabilize constantly repeating configurations such as the α- helix or β-sheet. In the same protein, different zones with different secondary structures will coexist.
- Tertiary structure: the general form of a single protein molecule; the spatial association between secondary structures. Nonlocal interactions with the forming of a hydrophobic heart normally stabilize tertiary structure. The basic functions of proteins are regulated by the tertiary structure.
- Quaternary structure: a structure created by several proteins that work together to create a single protein complex.

Proteins are categorized as fibrous, globular, or membranous based on their form and solubility. Fibrous proteins have linear, basic shapes. Globular proteins have a nearly spherical shape. The polypeptide chain is compactly folded, with hydrophobic amino acid side chains in the interior and hydrophilic side chains on the outside exposed to the solvent. They are highly soluble in water. Membrane proteins are present in cells in combination with different membrane systems. Membrane proteins have hydrophobic amino acid side chains directed outwards for contact with the non-polar process inside membranes. In general, they are insoluble in aqueous media.[39]

2.3. Polyesters

Polyesters based on agro-resources

Some bio-based polyester, such as PLA (Fig. 8) and PHAs, are now widely available, with varying industrial productions.

2.3.1. Poly (Lactic Acid) or PLA

The most thoroughly researched biodegradable and recycled thermoplastic polyester is PLA. Lactic acid is a chiral molecule that exists as two stereoisomers, L- and D-lactic acid, and can be formed in two ways: biologically or chemically. Lactic acid is produced in the first case by the fermentation of carbohydrates by Lactobacillus bacteria or fungi. To allow bacteria to develop and produce lactic acid, this fermentative process requires a bacterial strain as well as a carbon source (carbohydrates), a nitrogen source (yeast extract, peptides, etc.), and mineral elements. The lactic acid that is produced is almost entirely L-lactic acid, and the polycondensation process results in poly (L-lactic acid) (PLLA) with a low molecular weight.[40]
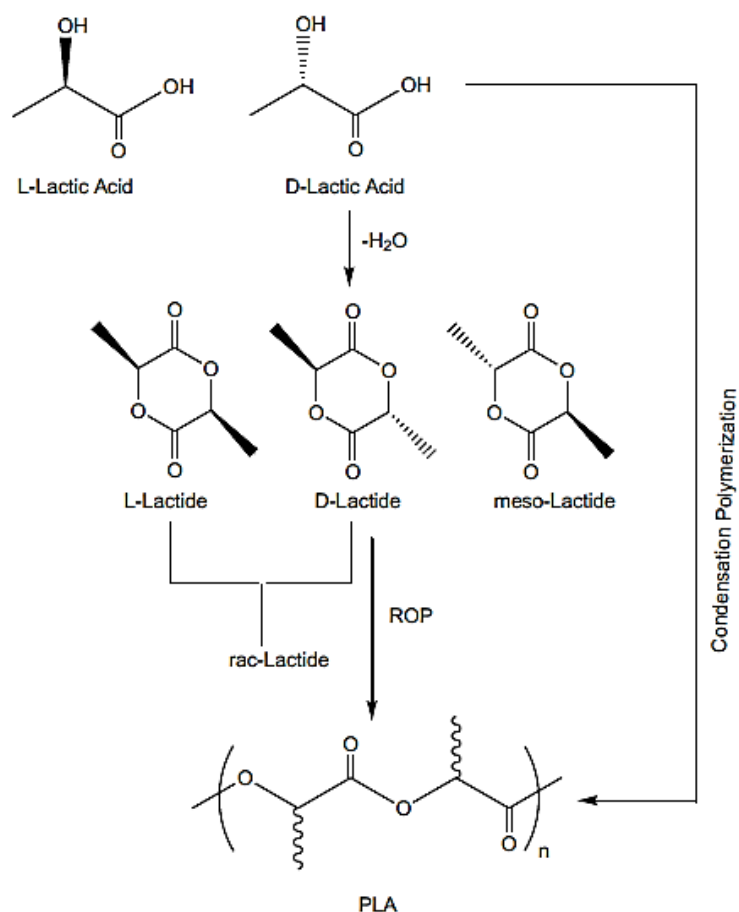
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24

Fig. 9. Schematic synthesis of PLA from lactic acid and lactide
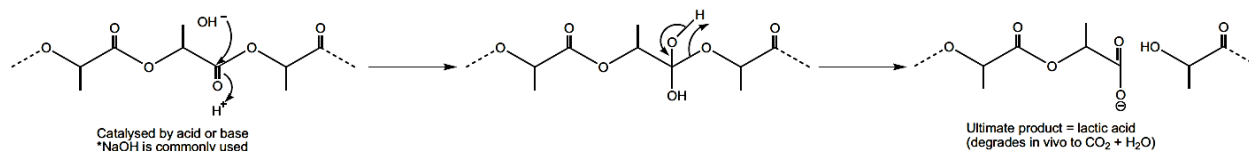

Fig. 10. Chemical degradation of lactic acid.

Lactic acid polymerization to PLA may be accomplished directly through condensation; however, the most common approach necessitates an initial conversion of lactic acid to a cyclic dimer intermediate, lactide. Lactide has three stereoisomers: D-lactide, L-lactide, and mesolactide. The lactide monomer can then be ring-opening polymerization (ROP) to generate PLA, with the stereochemical structure of the lactide isomers determining the polymer's final properties (Fig. 9). As an intermediate stage in the development of PLA, the chemical reactions that result in the formation of a cyclic dimer, the lactide, could lead to long macromolecular chains containing L- and D-lactic acid monomers. The development of two enantiomers of ROP from lactide is explained by this mechanism. This ROP route has the advantage of achieving a high molecular weight and allowing regulation of PLA final properties by varying the proportions and sequencing of L- and D-lactic acid units. Currently, about 30% of lactic acid is used in the manufacture of PLA. As a result, this biopolymer has a high growth potential. PLA, despite arguments to the contrary, is most likely not biodegradable. However, it is chemically degradable (Fig. 10).[41]

PLA (Fig. 11) has the ability to achieve various microstructures or tacticities in the polymer chain, which is one of the most significant characteristics. The properties of the polymer chain can be altered by varying the microstructure. Stereo-controlled ROP of meso-lactide produces either syndiotactic PLA or heterotactic PLA with stereocenters that alternate twice. By alternating the addition of D- and L-lactide enantiomers, Rac-Lactide may also contribute to heterotactic PLA. Rac-lactide can also generate atactic and isotactic PLA. PLA is a polymeric helix that has an orthorhombic unit cell. PLA properties are affected by component isomers, processing temperature, annealing time, and molecular weight. PLLA is the end product of L-lactide polymerization. PLLA has a crystallinity of approximately 37%, a glass transition temperature of 50–80°C, and a melting temperature of 173–178°C. Optically pure polylactides, PLLA and poly (D-lactide) (PDLA), are semicrystalline due to their stereo normal chain microstructure (Fig. 12).[42]

When quenched from the melt, polylactide is a clear, colorless thermoplastic that is identical to polystyrene in several ways. Polylactic acid, like most thermoplastics, can be converted into fiber
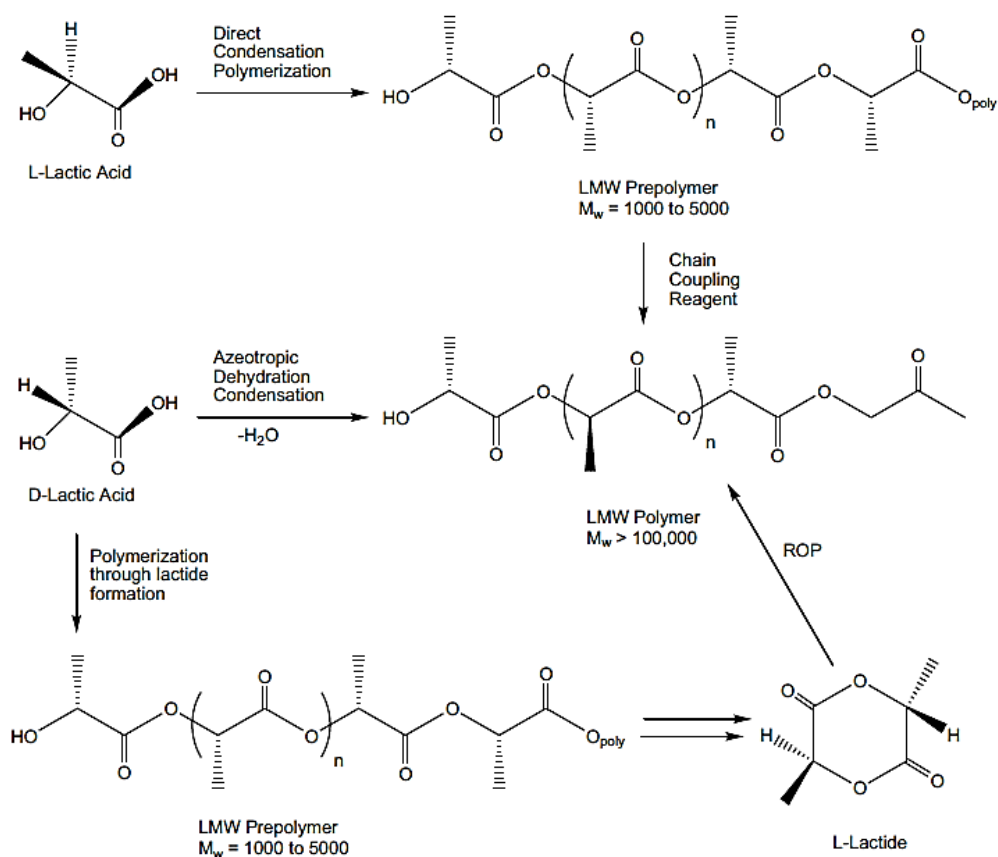
Fig. 11. Chemical structure of PLA and Synthesis methods for obtaining high molecular weight.[42]
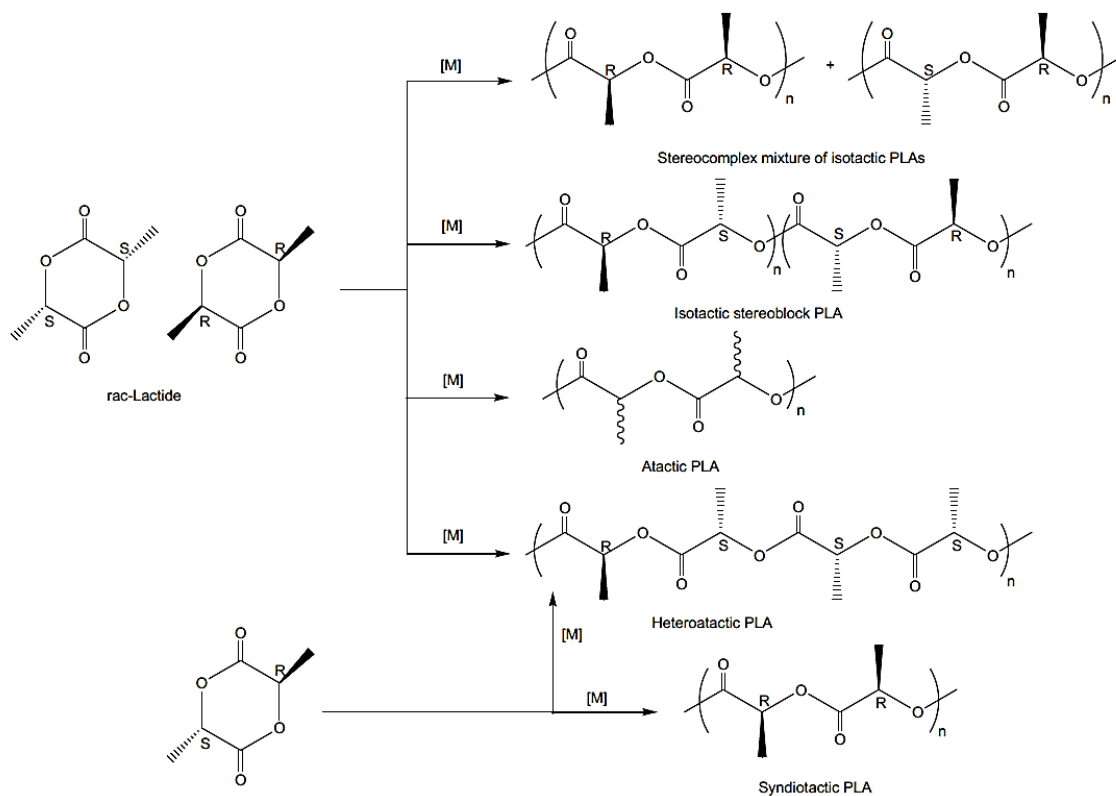

Fig. 12. Schematic diagram showing PLA microstructures from the stereo-controlled ROP of lactide.
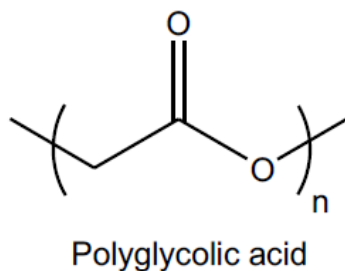
Fig. 13. Structure of PGA.

and film. By physically mixing the polymer with PDLA, the melting temperature of PLLA can be raised by 40–50 °C and the heat deflection temperature can be increased by 60–190° C. PDLA and PLLA combine to form a strongly normal stereo complex with high crystallinity.[40]

PLA research has advanced to the point that it is now a prominent commodity in the field of synthetic polyesters. Other PLA compounds, such as its copolymer poly lactic-co-glycolic acid (PGLA), in which lactide and glycolide are copolymerized, are also of great concern. PLA is recommended as a commodity resin for general packaging applications because it satisfies many standards as a packaging thermoplastic. PLA becomes more versatile when plasticized with its own monomers, allowing for the production of a continuous sequence of materials that can imitate PVC, low density polyethylene (LDPE), linear low-density polyethylene (LLDPE), polypropylene (PP), and polystyrene (PS).[43]

2.3.2. Poly (lactic-co-glycolic acid) (PLGA)

Lactic acid and glycolic acid are the monomeric units of PLGA. Because of the reversibility of the condensation reaction, backbiting reactions, and the high degree of reaction needed, highmolecular-weight polymers of glycolic and lactic acid cannot be obtained by direct condensation of the corresponding carboxylic acids. As a result, polyglycolide and polylactide are normally synthesized by ROP of their respective cyclic diester dimers, glycolide and lactide. Since biodegradable polymers have the ability to be used in bioresorbable surgical systems, there has been a significant amount of research into drug delivery using biodegradable polymers over the last 30 years. PLGA is a Food and Drug administration (FDA)-approved substance with good physical properties and high biocompatibility, making it a pioneer in the production of novel materials for drug delivery systems and tissue engineering scaffolds. It has been thoroughly researched for drug distribution, protein delivery, and the delivery of other macromolecules such as deoxyribonucleic acid (DNA), ribonucleic acid (RNA), and peptides. Furthermore, PLGA has demonstrated favorable degradation properties, making it a viable candidate for long-term drug release via implantation without invasive surgical procedures. The most basic linear aliphatic polyester is PGA (Fig. 13). As degradable and absorbable sutures, both PGA and the copolymer PLGA are used. Their primary benefit is degradability in aqueous environments, such as body fluids, through simple hydrolysis of the ester backbone. Furthermore, breakdown products are eventually metabolized to carbon dioxide and water or are excreted from the body through the kidney.[44]

For several years, the polymers in this family have been used as parts of biodegradable sutures and orthopedic implants, giving them a long history of use in the human body. Many characteristics of PLGA systems make them ideal for drug delivery applications requiring a gradual release of a drug inside a device. The following are some of the most important characteristics:[45]

- The ability to monitor the kinetics of polymer degradation.
- A variety of fabrication paths.
- Attractive mechanical properties
- Medical grade is widely available.

3. Conclusions

In this review, we have discussed synthesis, structure, properties, and applications of this particular class of polymers. In particular, the two major types of biodegradable polymers, agro-polymers (such as starch, chitin, protein, and so on) and biodegradable polyesters [polyhydroxyalkanoates, poly (lactic acid), and so on] are mainly discussed.

Conflicts of Interest

The authors declare no conflict of interest.

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