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A REVIEW ON ECOFRIENDLY POLYMERS AND THEIR POTENTIAL APPLICATIONS IN BIOMEDICAL SCIENCES

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ABSTRACT Eco-friendly polymers are biodegraded by microorganisms, making it easy to transform them into safer, more straightforward forms. These biodegradable materials can be used in a variety of industries, including medicine, agriculture, drug release research, food and medication packaging, and artificial skin grafts. It prevents environmental accumulation and cannot result in pollution of the land, air, or water.

KEYWORDS : Polymers, Biodegradation; Applications

INTRODUCTION

Synthetic polymers extensively used in various applications from space and aviation to household and material integrity. Many herbivores animals, seabirds and mammals die every year from ingestion of traditional plastic. Global implementation of biodegradable polymers for various mankind purposes is a major challenge[1].

Biodegradation is a natural process through which complex organic compounds in the environment were converted to simple compounds, then mineralized and redistributed through biogeochemical cycles. Such polymers can be extensively employed in various fields like medical, agricultural, drug release studies, food and drug packaging, artificial skin grafts and orthopedic devices.[2-3]

ECOFRIENDLY POLYMERS

In general, biodegradable polymers are those that are created naturally during the growth cycles of organisms or those that are consumed by microorganisms as food.

Starch and Cellulose

Cellulose and starch are most abundant polymers in nature with wide applications. Both are composed of hundreds or even thousands of D-glucopyranoside repeating units. Enzyme catalysed different acetal hydrolysis reactions during the biodegradation of each of these two polysaccharides. Many crops and plants contain starch and it is formed by alpha-1, 4-linkages in amylose and amylopectin. Film casting requires starch and cellulose polymers. Acetylated starch has been employed as a structural fiber or film forming polymer. Many crops and plants contains starch and it is formed by alpha-1, 4-linkages in amylose and amylopectin. Film casting requires starch and cellulose polymers. Acetylated starch has been employed as a structural fiber or film forming polymer[4-5]. Like starch-polyethylene blends, starch-Polyvinyl Alcohol, starch low density poly ethylene and starch poly ethylene-co acrylic acid blends are used to cast degradable agricultural mulch films based on urea and ammonia supplementations. Similarly, starch added into PVC used for making disposable plastics and agricultural devices. Number of starch based resins prepared with reactive isocyanides and urethane systems to make flame resistant, solvent resistant, high tensile strength polymers, which are readily attached by soil microorganisms.

Cellulose esters represent important class of polymers, which is an integral participant of Carbon cycle via microbial decomposition. The possible mechanism of cellulose ester degradation takes place via enzymatic cleavage of the acetals by esterase and by cellulolytic enzymes. From the last few decades, increased attention is being given to more complex carbohydrate polymers produced by bacteria and fungi, those composed of Xanthan, Curdlan, Pullulan and Hyaluronic acid units. All of these are heteropolymers with regularly arranged branched structures.

Chitin

Most of the common structural polysaccharide found unanimously in shells of crabs, lobsters, shrimps and insects is chitin. Chitin is formed by 2-acetamide-2-deoxy-b-D-glucose through the β-(1-4) - glycoside linkage and degraded by chitinase. Native Chitin and partially deacetylated chitosan are used for making artificial skin, absorbable sutures and heavy metal absorbents. Due to water binding ability and moisturizing property finds several applications in cosmetic industries and in preparation of wound healing agents. Like polyglycollic acid, Chitin derivatives were excellent drug carriers of water soluble prodrugs because of its lowest longetivity shown in tissue reaction.

Alginate

Unlike other polysaccharides Alginate polymer is composed of two saccharides viz 1, 4-linked α-L-guluronic acid and β -D-mannuronic acid. Alginate polysaccharides has ability to form gels with divalent cations such as Ca^{2+},Be^{2+}, Cu^{2+}, $Al^{3+}$and Fe^{3+}. Alginate gel beads used as drug delivery vehicles due to ability of controllable drug release. Even proteins and enzymes are incorporated widely in alginate beads for drug delivery and also used in bioreactor design. Alginate has also been used for whole cell immobilization, herbicides and microbial encapsulations.

Polypeptides of natural origin

The fibrous proteins wool, silk and collagen have found applications as materials. Such proteins for the most part, are insoluble and unbreakable without degradation. These proteins are copolymers with regular arrangements of different types of α-amino acids; hence biosynthesis of proteins is an extremely complex process. Such peptide origin polymers degraded by amide hydrolysis reaction via proteolytic enzymes.

Gelatin

Gelatin, is an animal protein, consists of 19 amino acids joined by peptide linkages and can be hydrolyzed by a variety of the proteolytic enzymes to yield its constituent amino acids or peptide components[6]. Gelatin is a water-soluble, biodegradable polymer with nonspecific hydrolysis used desirably in degradation. Gelatin films are fused with antimicrobial compounds and used in the treatment of open wounds. Before wound applications of gelatin films were often sterilized with γ-rays. With slight Chemical modification of natural polymers by grafting methyl methacrylate onto gelatins by radical initiators serves the two fold purpose of utilizing renewable, naturally derived products such as proteins, as replacements for petroleum-based polymers and as biodegradable compositions which can be tailored for the slower or faster rates of degradation.Various Bacteria like Bacillus subtilis, Pseudomonas aeruginosa, and Serratia marcescens can degrade such grafted polymers of gelatin with better efficiencies[7].

Polyesters

Polyester polymers are chain of monomers bonded by ester linkages. These thermoplastic biopolymers are degraded by Esterase enzymes of microbial origin. Organic polyesters accumulated by bacteria as stored food granules are known as Poly Hydroxy Alkonates (PHA).Polyesters obtained from of medium sized monomers (C_6–C_{12}) with two acidic functional groups are rapidly degraded by fungi (Aspergillus niger and Aspergillus flavus) and by bacteria in both aerobic and anaerobic conditions. Synthetic polymers are degraded by microorganisms when secrets digestive enzymes. Flexible Aliphatic Polyesters are biodegradable but rigid aromatic polyesters are not disintegrated[8-10].

Poly(glycolic acid)

Structure of Poly(glycolic acid) is simple, linear, and aliphatic polyesteric polymer. By using poly(glycolic acid-co-lactic acid) polymers, disposable, degradable and absorbable sutures are manufactured. Poly (ε-caprolactone) (PCL) is synthetic polyester. PCL films are most suitable for making controlled releasing devices with longer shelf life. Poly-L-Lactide (PLLA) is lactic acid based polyester used in biomedical and packaging applications. Polyesters derived from alkane diols and alkane dicarboxylic acids are low molecular weight biodegradable polymers. Such polyesters have less applications due to their poor physical strengths[10].

Polycaprolactone

Poly (ε-caprolactone) (PCL) is synthetic polyester. Phytopathogens like fungi produces enzymes like lipases, esterases and cutinase to degrade cutin and act as PCL depolymerase. PCL films are most suitable for making controlled releasing devices with longer shelf life. PCL and polyesters prepared from alkanediols and alkane dicarboxylic acids are combined together to form containers for growing seedlings in horticulture. PLLA is absorbed in humans and animals, therefore extensively incorporated in medicines. The degradation occurs both ways by non-enzymatic in humans and animals and by enzymatic mode in microorganisms[11].

Polyamides

Polyamide is another class of polymers, with similar amide linkage that is found in polypeptides. Biodegradation of Polyamides is very slow and therefore they are reported to be nondegradable. The degradation is reported by enzymes and microorganisms in case of low molecular weight polyamides. Some fungi like cladosporium cladosporioides, Aspergillus versicolor and chaetomium species could degrade it. However, bacteria like Agrobacterium radiobacter, Aceinetobacter johnsonii, psuedomonas sps, Alcaligens denitricans, C. acidovorans, and vibrio anguillarum were unable to degrade polyimide based polymers. Even aramid fibre was reported to be attacked by Aspergillus fungi. Polyamide structure is highly crystalline due to presence of strong interchain interactions, which might be a reason behind slow process of biodegradation. Copolymers substituted with amide and ester functional groups are degraded easily. If a Polymer has more ester content and minimum cross linking in polamide crystals, then it is rapidly degraded. Synthetic polyamides has repeating units of oligomers mouled into higher symmetries with highly ordered crystalline morphologies, limits the capability of enzymatic degradation.[12].

Polyurethanes and polyureas

Polyurethanes show structural properties like polyesters and polyamides. In general the biodegradability of polyurethane is dependent on whether the prepolymer is polyester or a polyether. The polyether like polyforethanes are not degraded by microorganisms, whereas the polyester polyurehanes are readily attacked. It was reported that, Proteolytic enzymes (papain, subtilisin) from Fusarium solanii, Cryplococcus lacirentii, Aspergillus niger, Aspergillus fumeigatus, etc.) were effective in decomposition of polyurethanes. The process of decomposition depends upon chemical composition of polymer and microbial consortia. Polyurethanes obtained from poly(caprolactone diol)s, and aliphatic or aromatic diisocyanates were degraded readily with long chain of polyester and polyurethanes obtained from aliphatic diisocyanates are decomposed earlier than polyurethanes obtained from aromatic diisocyanates[14].

Polyanhydrides

Polyurethanes are chemically poly(diamide)s. Polyanhydrides are fiber-forming polymers with good biocompatibilities and are very susceptible to hydrolysis. The biodegradability of polymers can be changed by changing native structure of a polymer. A hydrophobic polymer can be degraded by enzyme hydrolytic processes, both by fungi and enzymes[12]. During their erosion, progressive loosening or swelling of the matrix takes place and on this property release rate of the device depends. Those matrices are desirable that can erode heterogeneously by surface erosion with smaller diffusion rates. A hydrophobic polymer can be degraded by enzyme hydrolysis, both by fungi and enzymes[13].

POLYMERS WITH CARBON BACKBONES

Poly (Vinyl alcohol) and poly (vinyl acetate)

Vinyl (vinyl alcohol) (PVA) is the most readily biodegradable. PVA decomposition in soil mainly occurs due to enzymatic degradation by secondary alcohol peroxides especially studied in Pseudomonas, Flavobacterium and Acinetiobacter strains. During controlled chemical oxidation, PVA is converted to poly (enol-ketone) (PEK), which has a similar structure to PVA biodegradation. PEK is extensively applicable as a flocculent, metal-ion remover (chelates metal ions) and excipient for controlled release systems. The PVA can form complexes with a number of compounds and utilised in the detoxification of organism. It is also used as a polymer carrier for pesticides and herbicides.

Polyacrylates

Poly (alkyl acrylate)s and polycyanoacrylates generally resist biodegradation or slowly degraded in soil-burial tests for copolymers of ethylene and propylene with acrylic acid, acrylonitrile, and acrylamide. Poly (2-hydroxyethyl methacrylate), which swells in water to form a hydrogel, has been widely used in biomedical areas because of its good biocompatibility. The release rate of adsorbed Actinomycin from nanoparticles correlated well with the degradation of the poly (isobutyl-2-cyanoamidrofolate) nanoparticles. The polyacrylate nanoparticles synthesized by using b-lactamase inhibitors found to be effective against Methicillin resistant Staphylococcus aureus[14].

APPLICATIONS OF ECOFRIENDLY POLYMERS

Some of these methods are commercialized for their specialized nature, greater unit value and medical device applications.

Polymers	Field	Applications
Polyglycolide (PGA), Poly-L-Lactide (PLA) and their copolymers Polyglactin, Polydioxanones and polyglyconates Copolymers of L-lactide and ε-caprolactone-poly (CL-LA)	Medical field i)Surgical sutures	For treating deep cuts, tissue damage or in a bone fractures synthetic absorbable sutures because due to tissues compatibility. Bio absorbable elastic materials used in grafting and transplantation surgeries
Polyglycolide (PGA), Poly-L-Lactide (PLA), Polydioxanones, polyhydroxydiaxanones (PHD)	ii)Bone fixation	It is used For ligament augmentation and securing a ligament structure in internal splinting to allow for early motion of the extremities after operations and also used as marrow spacer to save autologous bone material, plug for closing the bone marrow and for endoprosthetic joint replacement.
Gelatin- Heparin complex	iii)Vascular grafts	as a temperory antithrombogenic surface and a sub structure for an anastomotic neointima
Photogelated cured films of mucopolysaccharides e.g. hyaluronic acids and chondronitin sulphate partially functionalised with photoreactive groups viz cinnamate or thymine	iv)Adhesion prevention	Mucopolysaccharide gels may aid injured tissue repair, such gels are photocurable and non-tissue adhesion prevention material that is biodegradable with maximum wound healing rates.

Collagen, Chitin, Poly-L-lysine Fibrillar collagen combined with gelatin Spongy mixture sheets derived from collagen laminated with gentamycin sulphate in polyurethane membrane	V) artificial skin	Synthetic polymers and cell cultures combined to form the synthetic composites used as template for growing cells and tissue cultures in vitro. Drug loading is used to suppress bacterial growth and minimized cellular damage used in wound dressing of superficial second degree burns, deep burns, donor sites and pressure sores. Biomaterials can be used for healing burns, skin substitutes or wound dressing material.
Degradable polymers such as poly (Lactic acid) and polyorthoesters Poly (DL-Lactic acid) oligomers plasticized with 1, 2 propylene glycol and glycerol	vi)Drug delivery systems	as carriers for targeted drugs at their specific site of action e.g. liver enzymes Plasticized biodegradable polymeric material is suitable for application as drug delivery system
Low density transparent polyethylenes, PVC, polybutylene or copolymersof ethylene with vinyl acetate	Agricultural field i)Agricultural mulches	Photodegradable polymers are of major interest because they increase the yields and causes ripening two weeks earlier. Plastic films are desirable because they conserve moisture, reduce weeds and increases soil temperature, therefore improving effective growth rate. Elimination of weeds, avoidance of soil compaction, fertilizer and water requirement also reduced.
Starch, Cellulose, Chitin, alginic acid and lignin	ii) controlled release of Agricultural chemicals	In situ polymer encapsulation of pesticides, fertilizers like urea is an inexpensive system designed for controlled release. System includes microcapsules, physical blends, dispersion in plastic, laminates, hollow fibres and membranes. It serves primarily to control the rate of delivery, mobility and period of effectiveness of the chemical components.
Polycaprolactone	iii)Agricultural planting containers	as small agricultural planting containers for automated machine planting of tree seedlings
Biodegradable polymers into a laminate film or film blend pullulans PHBV and Pullulan blends	Packaging industry	coating food items due to low oxygen permeability and edible for long shelf life
Polysaccharides based biopolymers e.g. starch, pullulan and chitosan, LDPE and starch blends Poly lactic acid (PLLA) Ecoflex: plastic based on polyester and starch Depart: polyvinyl alcohol product	i)coating and packaging	to manufacture biodegradable packaging items at a reasonable price including bags for fast food wrapping, rubbish bags, six pack rings and food containers and for coating and packaging films for groceries.

CONCLUSION

In recent years, there has been a lot of interest in degradable plastics and polymers, with a focus on biodegradation in particular. Under comparable exposure settings, the majority of manufactured high polymers only biodegrade extremely slowly, whereas naturally occurring polymers readily biode degrade in the environment. Materials can be somewhat protected from biodegrading through surface engineering and environmental control of the physical, chemical, and biological environments. In this context, a variety of biodegradable polymer applications should be taken into account.

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