Biodegradable materials for food packaging

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ABSTRACT

Shortage of resources in society today, the resources available for human use has become increasingly scarce. To packaging, for example, most packaging products are single-use, and turn to waste after use, and the product life cycle of them are very short, so consuming large number of resources consumed, in the same time, the ecological environment has also been an unprecedented threat. Recently, the demands for biodegradable and renewable materials for packaging applications have increased tremendously. This rise in demand is connected to the growing environmental concerns over the extensive use of synthetic and non-biodegradable polymeric packaging, polyethylene in particular. Today's smart consumer is looking for alternatives that are environmentally friendly, durable, recyclable, and naturally rather than synthetically derived. Therefore, the purpose of this article will be to focus on biodegradable and environmentally friendly packaging materials, their advantages and disadvantages.

Keywords: **packaging, biodegradable materials, renewable materials.**

1. *INTRODUCTION*

Packaging of foods protects them from contamination through the environment and furnishes nutritional information to the consumers[1] .In recent years, with the rapid development of global industrialization, people's quality of life has improved, and people are no longer satisfied with the quality of goods and purposes. the majority of people even choose goods based on the packaging of goods which cause the situation of excessive packaging become serious. As an important part of manufacturing, packaging industry should emphasize the development of environmentally friendly packaging. Packaging waste, those from non-biodegradable polymers in particular, has become a significant part of municipal solid waste, resulting in increasing environmental concerns. Now the whole world is declaring war on plastic and seeking alternatives to plastics. Biodegradable and edible food packaging materials have become a research hotspot due to the serious white pollution and health concerns [2]. In this sense, green packaging is and aspect of great importance in order to reduce the impact of waste and pollution, and to promote sustainable development [3]. In short, green packaging is the appropriate packaging that can be reused, recycled or degradation, corruption and does not cause pollution in humans and the environment during the product life cycle. Biopolymers, such as polysaccharides, protein and lipid have been developed into food packaging materials [4]. Natural polymer for food packaging can replace the non-biodegradable petroleum-based synthetic polymers at a low cost, thereby producing a positive effect both environmentally and economically [2].

2. *food packaging biomaterials*

2.1. *Characteristics of food packaging biomaterials*

Certain characteristics to be monitored for acceptable biodegradable material as a suitable package for foods are listed below [5].

- *They should allow a controlled oxygen transfer. Excess oxygen can lead to oxidative degradation of the food material, and lesser oxygen will also afect the respiration of food materials. Thus, the material should allow slow oxygen transfer.*
- *Act as a selective barrier to carbon dioxide and moisture.*
- *Able to maintain an internal gas composition to regulate ripening and extending shelf life.*
- *Prevent the movement of lipids.*

• *Strengthen structural solidarity and lessen the loss of volatile biological components. They should ease the mechanical handling of foods.*
• *Provide fexibility to include supplements such as antimicrobials and antioxidants.*
• *Act as a protective barrier against spoiling microbes.*

2.2. Biodegradable polymers

Biodegradable packaging material can be grouped under three key categories, as mentioned in Fig. 1 .

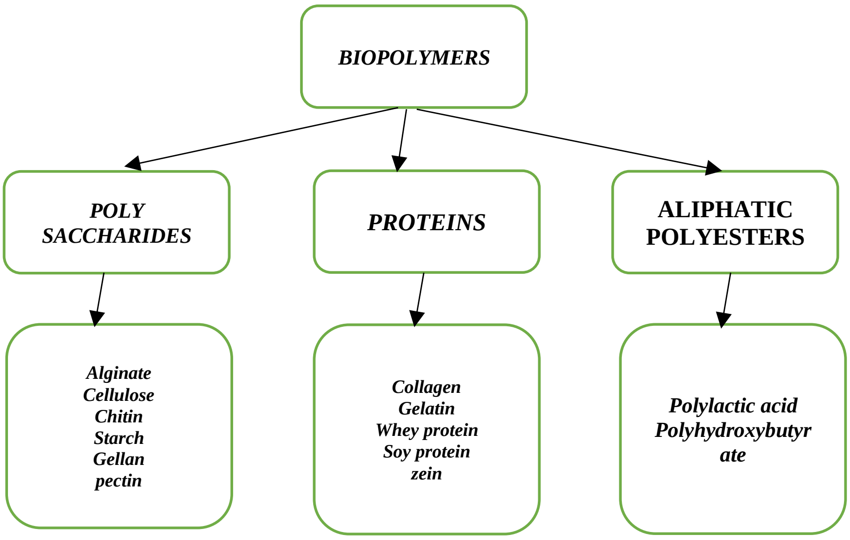

Fig. 1. *Classifcations of polymers*

2.2.1. Polysaccharides

2.2.1.1. Cellulose

Cellulose is linear homo polymer ofglucose which abundantly occurs in plantsand it acts as a reinforcement material inbacteria and plants. Structure andarray of hydroxyl group present incellulose tends to form strong hydrogenbonded crystal structure. It isthe basic structural component of plant cell walls non-digestible byman.Theglucoserepeat units are linked in the βconfiguration by contrast with the αconfiguration in starch. This allows thechains to crystallize in linear conformationin the form of highly crystalline, highaspect ratio and submicron diametermicro-fibrils that are aligned along thecellulosefibre known as single fibre [5-6]. Bacterial cellulose is even used to produce biodegradable flms by processing them into micro/nanofbrils and nanocrystals recorded the improvised elastic and tensile properties in bacterial cellulose (BC)-guar gum (GG) biodegradable flm by incorporating polyvinyl pyrrolidone (PVP)–carboxymethyl cellulose (CMC). Incorporation of microcrystalline bamboo cellulose in seaweed-based biodegradable flm reported enhanced mechanical toughness and elongation break point, makes it feasible to implement them as a constructive packaging material [7].

2.2.1.2. Chitin

Chitin is a natural polymer found in the cell walls of invertebrates, yeast, fungi, and some low-order plants. It is non-toxic, bio-compostable, and biodegradable. Researchers are improving the properties of its derivative, chitosan, by combining it with other polymers to enhance its mechanical, thermal, and permeability characteristics. Chitin is sourced from industrial processes involving fungal broth and crustacean shells, allowing for waste repurposing. To extract chitin, it is treated with sodium hydroxide to remove proteins, followed by hydrochloric acid to eliminate minerals. Chitosan, derived from chitin, is water-insoluble and can be used as a stabilizer. Chitosan films are effective in extending the shelf life of fruits like mangoes and can delay ripening. Modifications with enzymes or chemicals can enhance its properties. Chitosan exhibits antimicrobial properties due to its amino groups, making it suitable for sustainable packaging. However, information on its antimicrobial effectiveness is limited [8-9].

2.2.1.3. Starch

Starch, an abundant agricultural polymer found in plants like rice, wheat, beans, and potatoes, is gaining attention due to its accessibility, low cost, and eco-friendly properties. Its key components are amylose and amylopectin, with amylopectin constituting over 80% of starch granules. Starch exhibits film-forming capabilities through gelatinization, which disrupts its crystalline structure and allows for easy separation from other components. Techniques for film formation include wet and dry processes, and various starches, especially cassava, are used in food packaging. Plasticizers such as sorbitol and glycerol enhance the mechanical properties of starch films by increasing polymer chain flexibility and disruption of hydrogen bonds. Additives like antimicrobial agents and antioxidants are also incorporated to improve film quality. Current technologies, such as starch foaming, utilize processes like microwave heating and extrusion for developing starch-based packaging materials [10-11].

2.2.1.4. Alginate

Alginate is a biodegradable polymer commonly extracted from brown seaweed and certain bacteria. It is a non-repeating copolymer of β-D-mannuronic acid (M) and α-L-guluronic acid (G) and is known for its diverse structural properties influenced by environmental factors. Alginate serves various functions in the food industry, including as a thickener, gelling agent, and stabilizer in products like sauces and desserts. Its use in food packaging has been shown to extend shelf life, reduce microbial spoilage, and maintain food quality by preventing moisture loss. Studies indicate that alginate can enhance mechanical properties when blended with other compounds like silver nanoparticles and essential oils. The extraction processes differ between microbial sources and seaweeds, affecting the physicochemical characteristics of the alginate. Overall, alginate's applications in food preservation and packaging demonstrate its significant benefits in maintaining food quality and extending shelf life [12-14]. Packaging properties of alginate are : Tensile strength, Water solubility, Oxygen permeability, Thermostability, and Antimicrobial activity [5].

2.2.2. Proteins

2.2.2.1. Collagen

Collagens constitute about one-third of the total body protein inmammals and are structural proteins ofconnective tissue of bone,hide,tendons cartilage, and ligaments. Collagen is used as sponges,films, andmembranes. Commercially successful edible protein filmscan be made from collagen as it possesses characteristics as abiomaterial. These films have the following advantages: it has well-documentedstructural, chemical, physical, and immunologicalproperties; it is biocompatible and non-toxic to most tissues; and itis readily isolated and purified in large quantities. Theproduction of collagen films from animal hides using a dry or wetprocess with some similarities . Collagen fibrils provide tensile strength to animal tissues whichwere produced by self-assembly of collagenmolecules in theextracellular matrix. Collagen hydrolysis results in gelatin. Gelatinedible films reduce the migration of moisture, oxygen, and oil. Theirresearch has led to the conclusion that, collagen films are not asstrong and tough as cellophane, but have good mechanicalproperties. Collagen films have found to have excellent oxygenbarrier at zero percent relative humidity, but increased oxygenpermeability increases with increasing relative humidity in a waysimilar to that of cellophane. Carboxamide,microbialtransglutaminase, and glutaraldehyde are different cross-linkingchemical agents which were used to improve the mechanicalproperties, to improve the thermal stability of these films, and toimprove reduce their solubility [15-16].

2.2.2.2. Gelatin

Gelatin is a hydrocolloid that can form a thermo-reversiblesubstance with a melting point close to bodytemperature;thereforeit is particularly significant in edible film formation andpharmaceutical applications. Gelatin contains a high content ofglycine, proline, and hydroxyproline. Gelatin films contain a mixture ofsingle and double unfolded chains having hydrophilic character.Gelatin aqueous solutions at 40oC, are in the sol state and they formphysical, thermo-reversible gel on cooling. The chains undergo aconformational disorder–order transition and tend to recover thecollagen triple-helix structure during gelation. Gelatin films can beused as coatings on meats to reduce oxygen, moisture and transport ofoil. Gelatin is also able to form clear and strong films and can be usedfor microencapsulation as well as capsule coatings in food andpharmaceuticalmanufacturing. However, gelatinfilms do not possess ideal water vapor barrier, as compared to proteinfilms, which limits its application as edible films [17-18].

2.2.2.3. Whey protein

Whey obtained as a by-product in cheese, is produced in large quantities and has excellent functional properties and could potentially be used for edible films. Utilization of the excess whey in the form of whey protein concentrate (WPC) could effectively alleviate the whey disposal problem by their conversion into valueadded products, such as edible films and coatings. Whey protein films produce transparent, bland, flexible, water-based edible films with excellent oxygen and aroma barrier properties at low relative humidity. However, they have poor moisture barrier properties due to their hydrophilicity and/or to the level of plasticizer added to filmogenic solutions [19].

2.2.2.4. Soy protein

Soy is a cheap and renewable source of biopolymers, which has a great potential to replace petrochemical polymers in many applications. Soy protein (SP) is commercially available in three various SP concentrations: soy flour (54%), soy concentrate (65-72%) and soy isolate (90%). Molecules of SP include 20 different amino acids with strong inter- and intramolecular interactions. Such interactions make SP unmeltable and therefore it is impossible to process SP in the form of a thermoplastic polymer, unless a sufficient amount of plasticizer is used. The use of a significant amount of plasticizer results in low mechanical properties of SP plastics. On the other hand, when the plasticizers migrate away from the SP plastics during storage or service, the materials become very brittle. Moreover, the hydrophilicity of SP and the plasticizers leads to low moisture resistance of SPplastics. Blending of SP polymers with biodegradable polymers is a natural choice to overcome the said lack of SP-based polymers. The polymers used for mixing with SP are hydrophobic and therefore cannot establish a strong bond with SP and a compatibilizer such as maleic anhydride is required in the mixture. By adding it in a smaller amount, it is possible to improve the mechanical properties, the resistance to moisture and the viability due to the increased interactions within their compounds [20-21].

2.2.2.5. Zein

Most important protein in corn is zein. In 2002, it was found that zein being a prolamin protein dissolvesin 70–80% ethanol. Due to the high content of non-polar amino acids zein is relatively hydrophobic andthermoplastic. Films made from an alcohol soluble protein zein show relatively high barrier propertiescompared to other proteins. Zein films were formed through the development of hydrogen,hydrophobic and the presence of limited disulfide bonds between zein chains. There is adevelopment of hydrophobic and hydrogen bonds between zein chains in the film matrix. The addition ofplasticizer for increasing the flexibility of the films makes them non-brittle. Zein films offer goodwater vapor barrier properties as compared to other edible films. Zein films showed the ability to reducemoisture, loss of firmness, and delay colour change in fresh fruits by the reduction of O_2 and CO_2 transmission. Zein shows high water vapor permeability compared with typical synthetic polymers apartfrom the fact that it is not water soluble at a neutral pH. Addition of fatty acids or by using a cross-linkingreagent water vapour barrier properties of the films can be improved [22].

2.2.3. Aliphatic polymers

2.2.3.1. Polylactic acid

Renewable resources like sugar, corn, etc. produce lactic acid monomer by fermentation. Polylactic acid (PLA) is one of the most important biopolymers, obtained by depolymerization of lactic acid monomers. PLA is used for film packaging because it has a high molecular weight, high transparency, high resistance to water solubility and good processability. PLA is a crosslinking copolymer poly-L-lactic acid and poly-D-lactic acid. The PLA organoclay mixture was first prepared by dissolving PLA in hot chloroform in dimethyldistearylammonium, thus a solid tactoid formation was observed. The gas permeability of PLSNM decreased when the organoclay content of PLA is increased. Compared with other nano-classes, the oxygen scavenging properties of PLSNM with Cloisite 30B were very significant. PLA can be immobilized with many organoclays such as hexadecyl amine-MMT (C16-MMT), dodecyl trimethylammonium bromide MMT (DTAMMT), Cloisite 25A [23]. A good interaction was observed between the nanocomposites of amorphous PLA and chemically modified kaolin, followed by a 50% increase. Oxygen barrier properties. Nanocomposite materials derived from PLA are widely used to study their biodegradation in the environment among biobased nanocomposites. Degradation of polymers such as PLA proceeds through the following six steps (I) water absorption, (ii) hydrolysis of the ester bond, (iii) decomposition of oligomers, (iv) dissolution of oligomer fragments (v) molecular transfer of soluble oligomer (vi) possible decomposition into CO2 and H2O.

Therefore, the degradation of the polymer reaches a higher rate which increases the hydrolysis tendency of the PLA matrix. Although the hydrolysis pattern of PLA and its nanocomposites is quite similar, the decomposition of PLA nanocomposite was very high compared to polylactic acid due to the hydroxylated end groups in the clay layers. PLA nanocomposite was prepared by melt cross-linking method using different proportions of clay to control the biodegradability of the nanocomposite [24]. The extent of biodegradation of PLA films was measured using two methods. The first method was to calculate the amount of lactic acid released. The second method was to measure the mass change of PLA composition during hydrolytic degradation. Compared to the PLA, the PLA nanocomposite showed more of ten times higher than PLA (according to the first method) or 22 times higher (according to mass change). The category of clay and its concentration affect the rate of biodegradation. Tests were performed on the hydrolytic deterioration of PLA and its nanocomposite using only phosphate buffer solutions. The biodegradation of PLA nanocomposite was higher compared to polylactic acid. Therefore, the more hydrophilic the filler, the more pronounced the degradation will be. PLA-based packaging finds its application in beverage packaging in countries such as America, Europe and Japan [25]. Commercially packaged foods using PLA-based packaging materials include juices, water, milk, yogurt, cheese, and butter.

2.2.3.2. Polyhydroxybutyrate

According to food science, polyhydroxybutyrate (PHB) can be used for nutrient delivery, encapsulation of dietary supplements and development of packaging materials. PHB films exhibit Fickian diffusion kinetics when incorporated with antimicrobial agents. This allows for effective control of the growth of several microorganisms. Incorporation of vanillin (4-hydroxy3-methoxy benzaldehyde) into PHB at approximately 10 to 200 µg/g was performed to examine the growth of bacteria including E.coli, S. fexneri, S. typhimurium and S. aureus and the fungal growth consists of A. fumigates, A. parasiticus, A. favus, A . niger, A. ochraceus, P. clavigrum and P. viridicatum, respectively [26-27]. Expressed PHB movies a greater inhibitory effect against fungi compared to bacteria. Since smaller particles have the mechanism to penetrate cell membrane systems more easily, they are widely used against target microorganisms than larger particles. PHB is produced by the accumulation of carbon and energy by certain bacteria. The size of PHB is 0.5 µm and is present in the cytoplasm in granular form. Up to 90% of the polymer can be formed under suitable conditions in terms of bacterial dry mass. To isolate the PHB, it is necessary to disrupt the cell wall. It can be done by mechanical cutting, enzymatic digestion or by centrifugation, which leads to polymer extrusion. In the 1960s the first PHB was produced on the kilogram scale, but becomes brittle with age because of this stereochemical regularity and leads to progressive crystallization. This obstacle can be overcome by incorporating comonomers or related additives such as plasticizers. When eugenol is mixed with PHB, about 10 to 200 µg per gram of PHB inhibits the growth of S. aureus, E.coli, S.typhimurium, Bacillus cereus, A.favus, Aspergillus niger, Penicillium sp. and Rhizopus sp. [28]. The antimicrobial effect was improved when pediocin extracted from Pediococcus acidilactici was added eugenol at a rate of 80 µg per gram in PHB films compared to eugenol alone.

Polyhydroxybutyrate-co-3-hydroxy valerate (PHBV) was produced in 1970 in using several components in the culture medium. This improves the properties of PHBV but the market price of the copolymer is high and the conditions are toxic it also leads to lower productivity. Additionally, crystallization kinetics results in longer processing cycles. The possibilities of the application of PHB can be expanded with the application of the cooking method, which strengthens. The melting point of PHB is 180°C, the temperature of PHBV can be lowered to 137°C by adding 25% hydroxyl valerate. The introduction of hydroxyl valerate improves it lightness and mechanical stability of thermoplastics [29].

3. CONCLUSION

In conclusion, this review concentrates on the various sources of bio-based polymers and bioactive compounds and its production. With the growing awareness of depletion of non-renewable resources, it has become essential to find alternative materials derived from renewable resources and showing comparable properties to that of conventional plastics. Competitive bio plastics can be derived from natural feedstock(starch, cellulose, lignin, chitin, gelatine, casein, wheat gluten), microbial actions of microorganisms(PHB) or chemical syntheticmethods(PLA). Alginate was coated over the foods such as refned meat, carbohydrate sticks and onion rings. Collagen and aliphatic polyesters like PLA and PHB in combination with other polymers fnds importance to improve the stability and shelf life of food packaging materials. Biodegradable polymers fbers satisfy the environmental concerns, but they exhibit some limitations in heat resistance, gas barrier and mechanical properties associated with the costs. These types of packaging *materials need further studies, where nanotechnology feld comes into picture to improve the quality of packed food in terms of antimicrobial, antioxidant and nutritional values. It gives the consumer more delight to have detailed information about the product. To expand the functions and properties of the biodegradable flms, the incorporation of natural antioxidants and antimicrobial agents into polymeric matrices is necessary. The biodegradable packing materials should possess antimicrobial, antioxidant, antifungal properties along with enhanced tensile strength and prolonged shelf life with the advancements of newer technologies like starch foaming technology. Recent advances and applications of nanotechnology have given rise to antimicrobial packaging in retaliation to the drawback of food spoilage and losses. Thus, analyzing the flm's properties made from biopolymers is necessary to use as a replacement for harmful plastics.*

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