Prospects of Biopolymer as a Food Packaging Alternative

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Abstract: ***The synthetic polymers used for packaging of food originate from petroleum resources which have led to serious ecological problems due to their complete non - biodegradability. Around 9% to 10% of them are recycled globally and the rest persist in the environment for centuries or are burnt which further leads to CO2 emissions. This necessitates urgent research and development of alternatives for food packaging which would not only be biodegradable and assist in preserving the shelf life of the food but also display additional advantageous properties like reduced antimicrobial activities and water permeation. This review elaborates the advancements emerging in the sustainable food packaging research area by offering a complete overview of the two most promising substitutes in the field of biodegradable food packaging namely, biodegradable polymers and nanocellulose.***

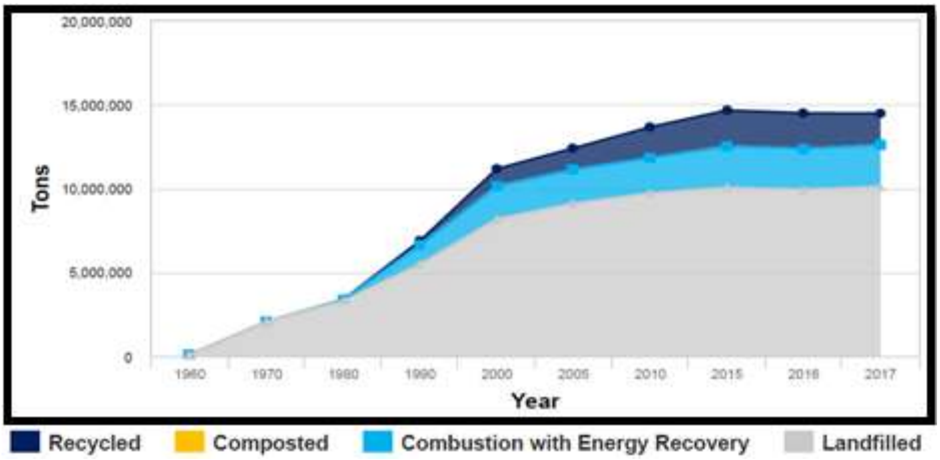
Keywords: Biopolymers, Packaging, Biodegradable Polymers, Food Industry, Nanocellulose, Film Properties, Bioplastics

1. Introduction

With the current global consumption of plastics estimated to be more than 200 million tonnes and an annual expected growth of approximately 5%, disposal of plastics is one of the biggest global concerns right now. One sector which predominantly utilizes plastic is the food sector, mainly because of it's large availability at relatively low cost, good mechanical performance such as tensile and tear strength, good barrier to oxygen, carbon dioxide, anhydride aroma compounds and heat sealability.

Most of the plastic in the food sector is of one time use and ends up in waste, polluting the environment as only some of it is recycled and the rest is disposed of in landfills and oceans due to technical and/or economical reasons. This results in the loss of valuable raw materials and the burning of packaging leads to CO2 emissions. Plastic packaging is mainly manufactured from oil and gas and hardly decomposes and ends up in the environment as litter. The increase in the amount of non - reusable plastic packaging has exceptionally increased environmental problems.

Since, the one - time use of plastic for packaging can't be changed it's the need of the hour to find biodegradable alternatives. This makes biodegradability an important functional requisite of packaging materials. Biopolymers offer a possible alternative to conventional plastics as food packaging material. A good packaging material must balance food safety with other issues, including energy and material costs, heightened social and environmental awareness and strict laws on pollutants and scrapping of municipal solid waste.



Food Packaging roles and materials:

A successful packaging process involves selection of the right packaging material and design that best satisfies the competing needs of the product and at the same time. The fundamental roles of food packaging materials are to protect food products from 3 main classes of external influences; physical, chemical and biological. The following are the properties that a good food packaging material must have -

Barrier properties

The determination of the barrier properties of a polymer is critical to estimate and predict the product - package shelf life. Water vapour and oxygen are two of the main permeants studied in packaging applications. Carbon dioxide is important for the packaging in modified atmosphere (MAP technology) because it inhibits the bacterial growth in processed fresh products, leading to a significantly longer shelf life. The particular barrier requirement of any food package depends on its product characteristics and its intended end use.

Oxygen transmission rate (OTR)

The oxygen barrier property of a fresh food product packaging is crucial to preserve it. Hence when a polymer film packaging has a low oxygen permeability coefficients, the oxygen pressure inside the packaging drops to the point where the oxidation is retarded, extending the shelf life of the product.

Water vapor transmission rate (WVTR)

The water vapour barrier properties for the packaged food product whose physical or chemical deterioration is related to its equilibrium moisture content, are important for maintaining and extending its shelf - life. For fresh food products it is vital to avoid dehydration while for bakery it is crucial to avoid water permeation.

Carbon dioxide transmission rate (CO2TR)

The carbon dioxide barrier properties of a food package helps to control the bacterial growth of the product. It is beneficial for food preservation and is used as a flushing gas in modified atmosphere packaging (MAP) it is also used to protect foods from oxidation.

Chemical resistance properties

Chemical resistance can be defined as the ability of a substance to protect itself from chemical attack for a specific period of time. The packed products tend to have weak and strong acidic characteristics, so it is essential to assess the performance and the suitability of the materials stored with common food packaging solutions as a function of time. The chemical resistance is normally determined by exposing the materials to weak acid (pH ¼ 6, acetic acid solution) and strong acid (pH ¼ 2, hydrochloric acid solution) for a period of 0, 1, 3, 5 and 7 days.

Classification of biopolymers:

First Generation

The first generation of biomaterials is composed of a mixture of low density polyethylene and starch fillers with a proportion of 5 - 15% material and pro - oxidizing and auto oxidative additives. These materials are non - biodegradable and degrade into smaller molecules that persist in the environment. These materials created a very bad image of biopolymers/ bio plastic with respect to being sustainable for the environment as consumers believed them to be biodegradable.

Second Generation

The second generation of biomaterials consists of a mixture of pregelatinized starch (40–70 %) and low density polyethylene (LDPE) with the addition of the hydrophilic copolymer such as ethylene acrylic acid, polyvinyl alcohol and vinyl acetate, which are used to compact. Complete degradation of starch takes 40 days and the degradation of the complete above - mentioned film lasts 2–3 years.

Third Generation

The third generation of the material completely consists of biomaterials and can be divided into three categories according to the origin and production methods.1. Polymers extracted/isolated directly from biomass 2. Polymers prepared by classical chemical synthesis and bio - monomers 3. Polymers procured directly from natural or genetically modified organisms. Third generation biopolymers can be divided into three main categories according to their origin and method of production:

Polymer extracted/isolated directly from biomass

Polymers extracted from biomass are the most common polymers present in the market. They are derived from plant matter, marine and domestic animals. Examples are cellulose, chitin and starch, soy protein, whey protein, casein, collagen, etc., can be used individually or as a mixture with synthetic polyesters such as polylactic acid. These polymers are most used in food packaging as cellulose - based paper.

Starch:

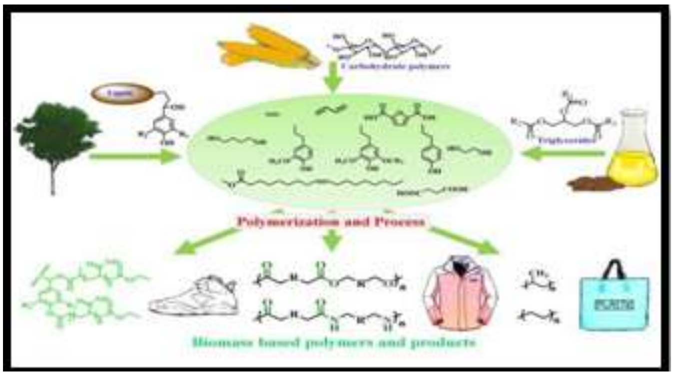
Starch is extracted from potatoes, corn, wheat and rice as it the main component in them. Due to its low cost availability and its production from renewable sources it is probably the most widely accepted biodegradable polymer. The properties of these materials vary as they can be stable or unstable in hot/cold water, depending on the starch percentage and other additives like flame retardant additives, colouring additives etc. Depending on the type of the thermoplastic starch materials, the degradation rate may vary from 5 days in aqueous aerobic environment, in 45 days in controlled compost and in water.

Chitin and chitosan soy protein:

Chitin and cellulose are structurally quite similar to each other and differ only by the hydroxyl group. It is abundantly present in the cell walls of some fungi and insect's skin and the shells of insects and shellfish. Chitosan is deacetylated derivative of chitin. Though Chitin and chitosan have poor mechanical properties and poro resistance to water, they have good antimicrobial properties to a variety of bacteria, yeast and fungi which are present in food which helps in preserving fruits for a longer time period thus increasing the shelf life of fresh foods and vegetables.

Other plant proteins:

Chickpeas and isolated soy proteins are the two most common vegetable proteins used for biodegradable food packaging. Unfortunately biopolymers from plant protein have not found major application as they have many drawbacks, they do not melt without decompression and are difficult to process due to which it's processing is expensive.



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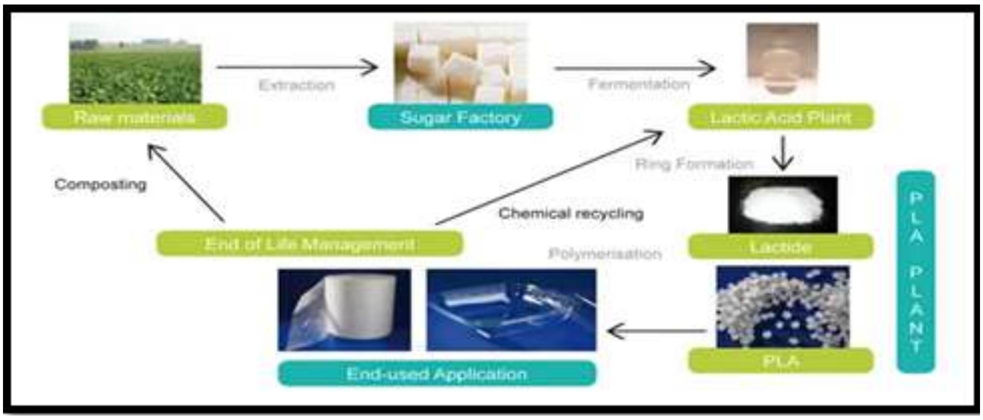
Polymers produced by conventional chemical synthesis of bio - monomers

Polylactic Acid (PLA) is presently a popular polymeric material which exhibits similar properties as polystyrene. Biopolymer is considered to play a vital role in building the circular bioeconomy

PLA is a biodegradable linear aliphatic–thermoplastic polyester produced either by the polycondensation of lactic acid or by the ring - opening polymerization of lactide with the latter being the most common. The ring open polymerization process utilizes various metal catalysts in combination with lactide to create the larger PLA molecules. Whereas, in the polycondensation process the lactic acid monomer is subjected to direct condensation. Lactide is a cyclic dimmer prepared by the controlled depolymerization of lactic acid, which is obtained from the fermentation of renewable resources such as sugar feedstock, corn, potato or sugar beets.

PLA is largely processed into thermoformed pads and containers for packing and serving food, flexible films, transparent bottles and other packaging materials. PLA has excellent water vapor - permeability which is important in the packaging of fresh food. This enables the water to evaporate quickly while reducing disturbance of the packaging. PLA has received considerable attention in food packaging applications with focus on films and coatings that are suitable for short shelf life and ready - to - eat food products. It has a high rate of recyclability and compostability. It is a versatile polymer with high transparency, high molecular weight, good processability and water solubility resistance.



Polyhydroxyalkanoates (PHAs)

Polyhydroxyalkanoates (PHAs) are microbial biopolymers (polyesters) that have a broad range of uses and applications. PHAs, synthesized by many bacteria as intracellular carbon and energy storage granules belong to the family of intracellular biopolymers. They serve in nature mainly as carbon and energy storage materials for a diversity of microorganisms.

In most cases, they are produced and accumulated under stressed conditions such as nitrogen, phosphorus, or oxygen limitation with excess carbon sources. Bacterial cells synthesize and accumulate the PHA polymers in response to nutrient limitation as an intracellular energy and food reserve. PHAs are polyesters and are a part of the living organism structure which are hydrophobic and insoluble in water. Enzyme PHA - polymerase catalyzes the reaction of polymerization HA in the PHA within the cell. The overall synthesis is carried out in the cell in a series of enzyme reactions. PHA, which synthesizes types Alcaligenes, Azotobacter, Bacillus, Halobacterium, Rhizobium and many other microorganisms can be produced in large quantities biotechnologically. Renewable substrate, using fermentation and known physical and chemical processes are extracted from biomass after production.

PHB and polyhydroxybutyrate - co - hydroxyvalerate (PHBV) are the most prominent biopolymers of the PHA family. PHB is a biodegradable polyester linear produced by bacterial fermentation of sugar or lipids. It can be used for food packaging, cosmetics and pharmaceutical products and well in agriculture. The aerobic conditions are completely degraded into water and carbon dioxide. It is expensive but it degrades in 5 - 6 weeks in a microbiology active environment, giving byproducts such as carbon dioxide and water in an aerobic condition. In an anaerobic environment the degradation is accelerated, with production of methane.

Mechanism of degradation:

The degradation of a polymer is caused due to the changes in its chemical and physical properties which may lead to loss in tensile strength, colour shape etc. It is caused due to various processes like mechanical, chemical, pollution contact, thermal, photolytic etc which may cause a change in the structure of the polymer chain in turn leading to reduction in the molecular weight.

Composting is a biological process in which polymers are degraded in controlled conditions at elevated temperatures by the activity of certain microorganisms. The resulting organic compost is completely environmentally neutral.

Biodegradation is a biochemical material conversion process by which organic substances are decomposed by the action of microorganisms into simpler substances like water, biomass, carbon dioxide or methane. The degradation process of biodegradable polymers may involve simultaneous or sequential biotic and abiotic steps, but the two major steps involved are fragmentation (reducing the polymer chain) and assimilation (process of resorbing).

There are various other mechanisms deployed for polymer degradation based on their physical and chemical properties such as, hydrolytic degradation, oxidative degradation, photolytic degradation and thermal degradation. Biodegradable and composting products are a friendly alternative to protect the environment in order to preserve fossil fuels and reduce carbon dioxide emissions.

Limitations of Biopolymers

The most important properties which are required for a material to be used as food packaging are barrier properties and mechanical properties. Biopolymers made from biomass have poor barrier properties to water thus limiting their use. Having low mechanical properties biopolymers can be brittle and not preserve the food item. Due to weak mechanical properties these polymers need to be mixed with synthetic polymers to improve their mechanical strength and increase their resistance to surrounding conditions. Another limitation of biopolymers is its high cost. However in recent years the price has dropped and will certainly reduce further with improved and optimised production technology. The availability of raw materials is still one of the most far - reaching problem that needs to be overcome. Therefore, it is important to develop methods to ensure the continuous supply of PLA, PHA or other raw materials to meet the demands of the food industry.

Methods for improving functionality

It is vital to develop new technologies and methods for the process optimization of biopolymers and to improve the barrier properties of bio packaging. To enhance the mechanical thermal and barrier properties. Nano cellulose can be incorporated in biopolymers. The incorporation of Nano composites improves the chemical and structural properties making them suitable for use in food packaging. There are different techniques that can be utilized to enhance various properties.

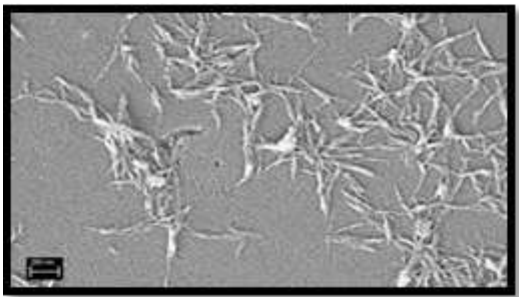
Nanocellulose:

Cellulose is the result of biosynthesis from plants, animals, bacteria, the cellulosic extracts or processed materials, having definite nano - scale structural dimensions. Nanocellulose is a light solid substance derived from plant matter which consists of nanosized cellulose fibrils. Nanocellulose, which is also called cellulose nanofibers (CNF), micro fibrillated cellulose (MFC) or cellulose nanocrystal (CNC), can be prepared from any cellulose source material, wood pulp is conventionally used. These three types of cellulose products are currently used in food packaging. Cellulose nanostructures have paramount applications in the food sector as food additives and packaging films. They are used as matrices for a variety of materials with antimicrobial properties.

The inclusion of cellulose nanocrystals (CNC) in biopolymers for the fabrication of strong nanocomposites provide added value materials with greater performance and ample applications for the next - generation biodegradable materials. CNCs are an outstanding reinforcing agent because of their superior mechanical properties. They also have high gas permeability and can reduce the water vapor permeability of films. They balance the encapsulated bioactive compounds in biopolymers while allowing better control of their release into the food. It is anticipated that the development of nanocomposite films in the presence of CNC increases the food shelf - life, improves the food quality, and can serve as an active conveyor of substances like antimicrobial, antifungal, insecticide, and antioxidant compounds.

Bioactive polylactic acid films infused with CNC (PLA - CNC) have promising approaches for the preservation of food products against a wide plethora of foodborne pathogens. Synthesized PLA films comprising lignin nanoparticles (LNPs) and CNCs show significant antibacterial activity. Developed PLA films reduce the loss and damage caused by plant pathogens on unprocessed food. CNC's display excellent dispersibility and ductility in a PHA matrix due to their hydrophobic surface characteristics and narrow particle size.

The addition of CNC modifies the structure of the biofilms and enables a more controlled dissemination of the antimicrobial agent. This property increases the lifetime of the bioactive films that remain active over a prolonged period. Thus, Biopolymer films infused with CNC's show significant improvement in their tensile strength and exhibit higher barrier performance.



2. Conclusion

With rapid depletion of petroleum reserves and growing concern over the environmental impact of currently used synthetic packaging materials, the need of the hour is to develop new and improvised alternatives that can serve the same purpose as conventional plastics. Biopolymers have emerged as promising green materials due to their eminent degradability. Although these materials are begging to the environment because of their potential to create a sustainable packaging industry, their use has been limited due to their poor mechanical and barrier properties. These properties can be enhanced by inclusion of nanocellulose as fillers. Nanocellulose reinforced materials have proven to provide more promising barrier properties. Hence application of nanotechnology to the food sector has been progressing briskly; however the development of nanostructures and nanocomposite materials containing cellulose is much slow paced. Further research will be necessary in the field to amalgamate the existing guidelines for the safety and beneficial assessment of nanomaterials in the food sector.

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