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A REVIEW ON THE APPLICATION OF BIOPOLYMERS IN FOOD GRADE PACKAGING

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Abstract:

The sector of food packaging is growing quickly as a result of the increasing need for packaged and ready-to-eat foods. In this sector, paper and paperboard packaging, such as corrugated boxes, folding cartons, and liquid packaging boards, is anticipated to have quicker growth over the coming years than petroleum-based plastics. The move to a circular economy and the pursuit of sustainable goals are the driving forces behind this change. It is well known that petroleum-based polymers have a negative impact on our environment. As a result, research into natural polymer alternatives to synthetic ones is gaining momentum. These natural polymers have been thoroughly investigated as potential replacements for non-recyclable and non-biodegradable synthetic polymers, both individually and in different combinations. This paper provides detailed insight of literature review describing the possible use of biopolymers like starch, chitosan, proteins and poly lactic acid (PLA) along with paper to produce effective paper based food grade packaging material.

1. Introduction

Packaging materials is used to contain, preserve, and protect a product. It also provides good presentation and information required by the user/customer. The packaging should preserve the food from contamination and spoilage (by microorganism, moisture, gasses, light etc.). Polymeric materials can replace traditionally used food packaging materials like metals, glass, ceramics etc. The polymeric materials can provide good food packaging at low cost because it requires less material.

Few decades ago, packaging was done using metals, glass, ceramics etc. With the technological advancement these materials were replaced with plastic materials to provide enhanced barrier properties. To further produce a food packaging material with more advanced or better properties, it was coated / laminated with multiple materials (layer by layer). To produce a good quality packaging material without multiple coating, blending of nano materials in the chain structure of polymeric material can be done.

The search of economical strategies to enhance the transportation and shelf-life of food product has now become a major fundamental and technical objective of various researchers. The coating based on methods of physical evaporation under vacuum were found as the most effective way to improve the barrier properties of polymeric material since last many years (1). In last few decades due to research and development, the packaging material has shown advancement in optical, mechanical, thermal and barrier properties. Due to such advancement the generation of intelligent packaging system for effective food packaging has taken place

(2). The various packaging materials used today are petrochemical based, these show extraordinary barrier properties but are non-biodegradable due to which they ends up as land fill and cause serious environmental problems.

Sustainable packaging can be defined as packaging that utilizes environmentally friendly materials to wrap, store, and ship products, without causing any long- or short-term detrimental effect on the environment. The use of biopolymers as food packaging materials has certain limitations like inferior strength, thermal and barrier properties in comparison to that of petroleum-based polymers. The application of nanocomposite with biopolymeric material can enhance its strength, thermal and barrier properties so that it become a better packaging grade material (3). The addition of nano fillers like silicate, clay, titanium dioxide may not increase the thermal, mechanical and barrier properties of biopolymeric material but it can act as multifunctional material (antibacterial, scavengers etc.) which makes material suitable for active food packaging (4). To improve the inherent properties of such polymers they can be reinforced with nanofillers. The use of nano fillers enhances the barrier properties of nano composite because the resistance to diffusion gets enhanced due to tortuosity of the path (5).

The global food packaging market is projected to experience substantial growth and reach an estimated value of around USD 592.8 billion by 2032. This represents a robust compound annual growth rate (CAGR) of slightly above 5.3% during the period from 2023 to 2032. The food packaging market is poised for expansion due to various factors, including rising disposable income levels, the trend of shrinking households, and a growing global population (6). Among the different applications within the food packaging market, the bakery and confectionery product segment emerged as the dominant sector, contributing to over 27.0% of the total market revenue in 2022 (7). In 2022, paper and paper-based materials constituted more than 33.0% of the total market revenue in the food packaging industry. The remarkable growth of this segment can be attributed to its wide adoption as a sustainable alternative to non-biodegradable packaging solutions. Consumers and businesses alike are recognizing the importance of eco-friendly packaging options, and paper packaging aligns well with their environmental concerns (7).

In 2022, the food and beverage packaging market in India was valued at USD 31.75 billion. Looking ahead to the forecast period from 2023 to 2029, the market size is anticipated to witness significant growth, with a projected CAGR of 14.8%. This growth trajectory is expected to lead the market to reach a value of USD 85.9 billion by 2029. The Indian food and beverage packaging market is segmented by material into Paper & Paper-based, Plastic, Metal, and Glass. Among these segments, the plastic segment is expected to dominate the market during the analyzed period. This indicates that plastic packaging materials will hold a substantial market share in India. The bakery and confectionery products have a significant presence in the Indian food and beverage packaging industry (8).

In 2022, the market size of starch-based plastics was assessed at USD 1,804 million. It is projected to experience substantial growth, with an estimated value of USD 4,059 million by 2031. This indicates a CAGR of 9.43% during the forecast period from 2023 to 2031 (9). The bioplastics market in India is anticipated to witness significant growth, with a projected CAGR of 24.36%. By 2027, the market is expected to reach a value of US$ 1,420.870 million, representing substantial growth compared to its value of US$ 308.942 million in 2020 (10).

2. Biopolymers for sustainable packaging

Biopolymers are polymers that can be derived from natural sources, either through chemical synthesis using biological materials or through complete biosynthesis by living organisms. The biopolymers obtained directly from biomass tend to possess hydrophilic and somewhat crystalline characteristics, which can present challenges during the processing stage. However, these biopolymers do exhibit excellent gas barrier properties, making them well-suited for application in the packaging industry (11). Figure 1 provides a list of some bio-based materials suitable for sustainable packaging.

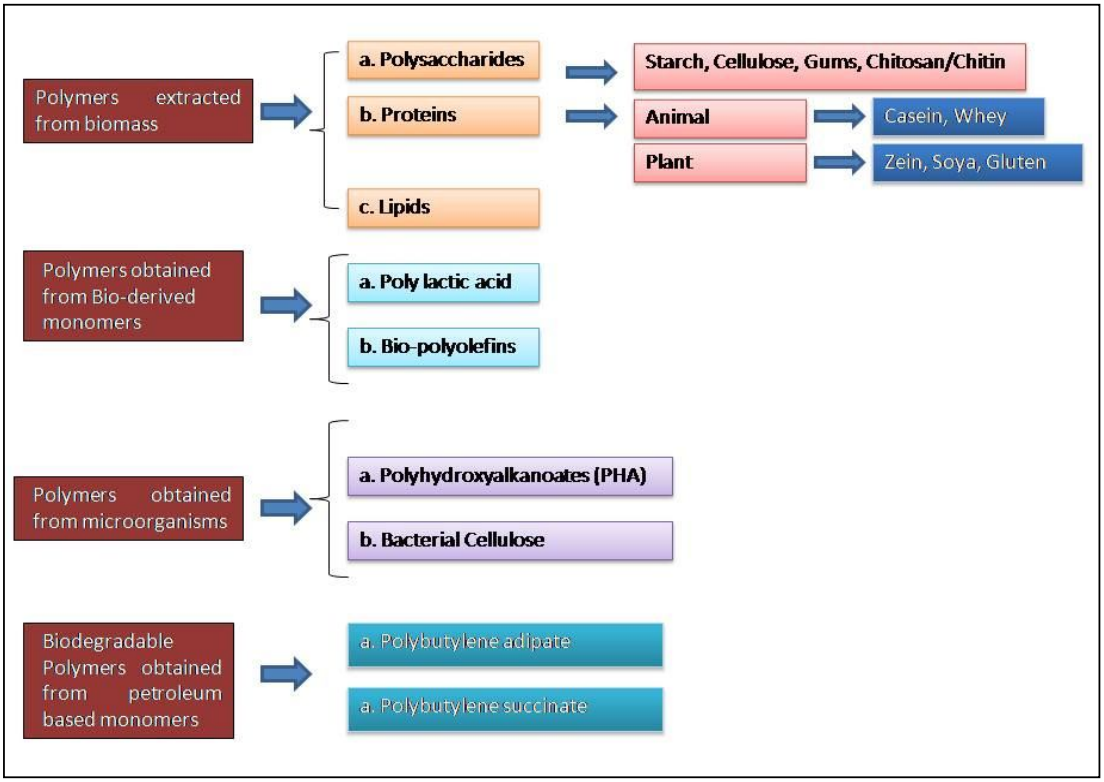

Figure 1: Biopolymers for sustainable packaging

3. Protein Based Packaging Material

Proteins consist of repeated units of amino acids linked together by peptide bonds. Proteins can have different reactive side groups in their side chains. Packaging extensively utilizes proteins due to their inherent qualities, such as their ability to form strong films, biodegradability, effective gas barrier properties, and high nutritional value. Additionally, proteins are widely available (12).

Gluten films exhibit high uniformity, excellent gas barrier properties, and good mechanical strength (13). The water vapor barrier property of wheat gluten films is relatively low due to the protein's hydrophilic nature, as well as the addition of plasticizers for flexibility (14). Soy protein films exhibit limited mechanical strength due to the presence of disulfide bridges, like gluten. However, the water vapor permeability of soy protein isolate films can be mitigated by cross-linking them with aldehydes (15). Whey protein offers good oxygen barrier properties, making it an ideal bio-based and biodegradable solution for blended, composite, or multilayer film structures (16). Corn zein [principal protein of maize] films exhibit superior barrier properties, particularly in terms of water vapor, compared to films made from other proteins (17). The combination of organically modified clay with soy protein offers dual benefits of enhanced thermal stability and reduced oxygen permeability in comparison to pure soy protein (18). The addition of organo-clay up to 20% in whey protein isolate improved its resistance to water vapor permeability (19). The incorporation of zein into starch reduces the water absorption of molded sheets compared to sheets made from pure starch (20). A multilayer structure consisting of zein, sorghum or carnauba wax, and oil demonstrates a substantial decrease of approximately 98% in water vapor permeability (21). The application of different proteins on paper/paperboard are given table 1.

Table 1: Impact of application of different proteins on paper/paperbaord

Subtract	Protein	Impact	References
Paper/ paperboard	Wheat gluten	Reduced oxygen permeability	22
	Whey protein and glycerol (60:40)	Increased the paper's resistance to oil without significantly degrading its strength properties	23
	Corn zein	Grease resistance of corn zein-coated paper is comparable to that of polyethylene laminate, making it a potential substitute for polyolefin materials	24
	Corn zein	Exhibits barrier properties similar to PE-coated paper	25

4. Starch and Chitosan Based Packaging Material

These materials can be easily produced by plasticizing the native starch. Starch consists of two different types of polymer 1) amylose (linear: molecular weight several hundred) and 2) amylopectin (linear: molecular weight several hundred). The amylose: amylopectin depends on the botanical origin, and it varies from rich amylose-based starch too rich amylopectin-based starch. The native starch can be modified to thermoplastic starch to providing treatments which promotes restructuring within the starch. This can be done by gelatinizing or by applying stresses (extrusion). The starch films are widely used to produce soluble films, loose films, bags and sacks etc. The effect of adding different materials with starch on the final properties of starch are given in table 2.

Table 2: Effect of adding different materials with starch on the final properties of starch.

S.No.	Main material	Other material added	Impact	References
1	Thermoplastic starch	Chitosan nano crystals/ chitosan nano fibers	Reduced oxygen permeability by 25-30 %	28
2	Sago starch and bovine gelatin	Zinc oxide nanorods	Reduced oxygen permeability by 40-55 %	29
3	Starch	lignin	Reduced water vapor permeability by 40-55 %	30
4	Thermoplastic starch	Cellulose nanofibers	Reduced moisture sensitivity of the material	31
5	Oxidized starch plasticized using glycerol	Nano clay	Increased young modulus of films by more than 70%	32
6	Starch and glycerol	Nano clay	Enhanced mechanical strength and resistance to water vapour barrier	33
7	Corn starch plasticized using glycerin	Kaolin clay	Enhanced the tensile strength and modulus	34

Chitosan is a pseudo natural polymer prepared by enzymatic and chemical deacetylation of chitin. It is a quite useful polymer due to its availability and nontoxic nature but still paper industries are unable to unlock/use this polymer up to its full potential. Chitosan comprises a linear sequence of monomeric sugars β-(1–4)-2-acetamido-2-deoxy-D-glucose (N-acetylglucosamine) and glucosamine. Chitosan possess antimicrobial properties against a wide range of fungi and bacteria. Due to presence of amino group chitosan become cationic in nature and it will assist it to better interact with the cellulosic fibers (26).

The strength properties of chitosan films are almost similar to polyethylene and cellophane (27). The chitosan films cannot be formed by extrusion and molding because chitosan is thermoplastic and it degrades before reaching the actual melting point. Different researches were carried out in for improving the quality of chitosan films. These researches includes like embedding the nano particles, clay, polysaccharide fibers, oils, antimicrobial agents, plasticizer etc. in chitosan. The application of chitosan as surface sizing chemical on paper are given in table 3.

Table 3 The application of chitosan as surface sizing chemical on different base paper

S.No	Base paper	Details of chitosan usage for surface application	Properties Improved	References
1	Handsheets made of unbleached Kraft bagasse pulp (68 g/m^2)	Degree of deacetylation: 85%. Paper sheets were dipped in different concentrations (0.05% to 0.75%) of chitosan solution for 30 seconds. The coat weight was in the range of 0.06 g/m^2 to 0.79 g/m^2.	Strength	35
2	Base paper made from bleached Kenaf kraft pulp	Degree of Deacetylation: 85.4% Molecular wt: 900000 Dalton chitosan solution used for surface application: 0.5% to 2% (done by spraying)	Strength and barrier	36
3	Base paper – (78 g/m^2)	(Chitosan in coated on precoated CMC sheets) Chitosan solution used for surface application: 1% Coat weight : 2 to 8 g/m^2 Degree of deacetylation: >75% Molecular wt: 150000 Dalton	Barrier, strength and thermal	37
5	Paper made of bleached kraft pulp (74 g/m^2)	Chitosan of 90% DD and 90000 g/mol molecular weight was used to synthesize the water soluble chitosan. chitosan solution used for surface application: 2% To achieve different coat weights (one to five layer coating was done using size press machine). One layer of chitosan and water soluble chitosan coating provides the coating of 0.76 g/m^2 and 0.68 g/m^2, respectively.	Strength and barrier	38
6	Base paper – printing paper (80 g/m^2)	chitosan solution used for surface application: 2%	Strength	39

5. Polylactic acid (PLA) Based Packaging Material

PLA is widely used bioplastic because it is renewable, biocompatible and biodegradable. PLA belong to the family of synthetic aliphatic polyesters. PLA is thermoplastic in nature. It has several advantages like good transparency, degradation in biological environment, biocompatibility, processability etc. when compared with petroleum-based polymers usually used in food packaging. PLA has certain disadvantages like thermally unstable, degrades during processing etc. due to which its usage as an effective material to produce packaging grade paper is still challenging (40). The effect of adding different materials with PLA on the final properties of PLA are given in table 4.

Table 4: Effect of adding different materials with PLA on final properties of PLA

S.No.	Main material	Other material added	Impact	References
1	Semi crystalline PLA	Organoclays	Reduced the OTR and WVTR by around 50%	41
2	PLA	Graphene oxide Nanosheets	Reduced gas permeability by around 45% (for oxygen) and 68% (for carbon dioxide)	42
3	PLA	Chitosan + clay	Reduced the OTR by around 99%	43
4	PLA	Silica	Improved transparency and reduced oxygen permeability (69%) and water vapour permeability (45%)	44

Paper coated with nanocellulose and further coated with PLA. The water vapor transmission rate of nanocellulose/ PLA coating was lower than that of only PLA coating. The composite structure of paperboard/nanocellulose/ PLA had shown 98% lower oxygen transmission rate in comparison to paperboard only coated with PLA (45).

Conclusions

Packaging serves not only as a means for storing, shipping, and selling products but also as a platform for presenting product information, quality, and brand identity. Traditional packaging based on petroleum fuels has become a major environmental concern, due to its non-biodegradable nature. The packaging industry plays a vital role in the global economy and if such non-biodegradable packaging will continue it will impact the world's lifestyle and economy. This raised global attention towards the production of biopolymers and use them in packaging as an alternative to petroleum based non-biodegradable packaging. Promising alternatives for petroleum based packaging are biopolymers derived from plants, animals, agricultural waste such as cereal straws, kenaf, bagasse, and other non-wood sources. The review paper summarizes different properties of various biopolymers alone and in combination with others to achieve a better food packaging material.

To address repulpability issue of paper/ paperboard in multilayer packaging material, one can utilize natural polymers either individually or in combination to create water-based barrier coatings. Such coatings, unlike their non-water-based counterparts, do not negatively impact the repulpability of paper or paperboard.

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