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BIOPLASTICS: THE FUTURE OF ECO-FRIENDLY PACKAGING MATERIALS

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1. Introduction

Biopolymer-based packaging materials have become of greater interest to the world due to their biodegradability, renewability, and biocompatibility. In recent years, numerous biopolymerssuch as starch, chitosan, carrageenan, polylactic acid, etc.—have been investigated for their potential application in food packaging.

Reinforcement agents such as nanofillers and active agents improve the properties of the biopolymers, making them suitable for active and intelligent packaging. Some of the packaging materials, e.g., cellulose, starch, polylactic acid, and polybutylene adipate terephthalate, are currently used in the packaging industry. The trend of using biopolymers in the packaging

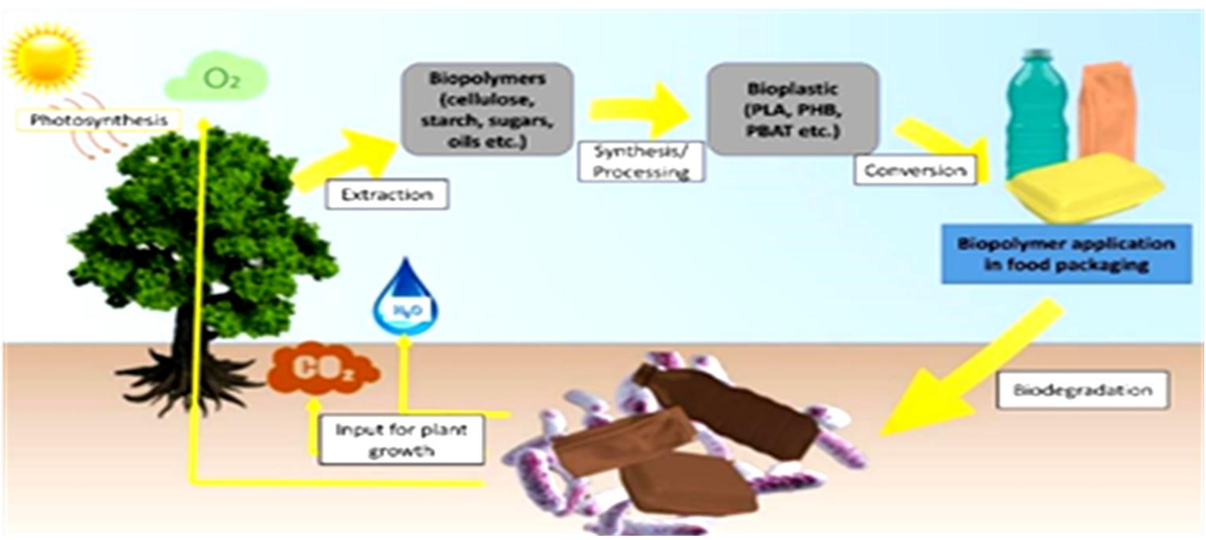

Fig.1. Bio-plastics overview

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industry has increased immensely; therefore, many legislations have been approved by various organizations (Horst *et al.*, 2020).

2. Advantages and disadvantages of different biopolymers in food packaging

Biopolymers such as starch, cellulose, and polylactic acid (PLA) are currently used for food packaging materials. However, the main limitation of using biopolymers in food packaging is their weak mechanical strength

Biopolymer	Positive Characteristics	Negative Characteristics
	Starch-based biopolymers	
Starch	• Biodegradable • Renewable • Nontoxic • Low cost • Abundance • Transparent • colorless, flavorless, tasteless • Good lipids, oxygen, UV barrier properties • Great film-forming ability • Low water vapor permeability	• Limited process ability • Poor water resistance • Low mechanical properties • Hydrophilic • Low thermal properties • Brittleness
Cellulose	• Biodegradable • Renewable • Nontoxic • Low energy consumption • High surface area • Good oxygen, hydrocarbon barrier properties • High mechanical strength • High water vapor permeability • Low cost • Low density • High specificity • Biocompatibility • Odorless, tasteless • Chemical stability	• Low mechanical strength • Opacity • Enhanced color value • Hydrophilic nature • Poor water vapor barrier properties
Pectins	• Biodegradable • Renewable • Nontoxic • Good oil, aroma, gas barrier properties • High mechanical properties • Good rheological properties • Cost effective • Good film-forming capacity	• Ineffective against moisture transfer • Poor mechanical properties • Brittleness • Poor thermal stability • High water solubility • Lack of antimicrobial properties
Chitosan	• Biodegradable • Renewable • Nontoxic • Increased absorption properties • High antimicrobial activity • High biocompatibility • Low production cost • Good gas, aroma, UV, oil barrier properties • Wettability • Antioxidant properties • water-insoluble • Good film-forming ability • Good optical properties • Transparent • Flexible	• Low mechanical properties • High hydrophobicity • Low water vapor barrier properties • Brittleness • Low elasticity
Lignin	• Biodegradable • Renewable • Nontoxic • Natural broad UV blocker • Antioxidant properties	• Low mechanical properties • Low barrier properties

and high sensitivity to moisture. The merits and demerits differ depending on the type of biopolymer used for food packaging. To overcome the weaknesses of biopolymers, many studies have been performed with the addition of reinforcing agents such as nanofillers, biopolymers, plasticizers, and natural agents such as essential oils. Furthermore, biopolymer matrices act as carriers for antimicrobial substances, antioxidants, flavor agents, vitamins, or nutrients, thereby aiding in improving food quality, safety, nutritional value, and sensory properties. An overview of biopolymers in food packaging is presented in Figure 2. Due to the numerous advantages, biopolymers have been proposed as an alternative to synthetic polymers such as plastic, which reduces the harmful impact on the environment (Matthews *et al.*, 2021).

3. Current Food Packaging Materials and Associated Issues/Challenges

Plastics account for about 6% of global oil consumption, projected to increase to 20% by 2050. Plastic waste damages terrestrial environments and pollutes aquatic ones, accumulating due to prolonged degradation. Landfill plastics release harmful substances during abiotic and biotic degradation, contaminating soil and water. Chlorinated plastics leach toxic chemicals, polluting ecosystems, while plastic degradation in water releases chemicals such as polystyrene and Bisphenol A, causing water pollution. Methane and CO_2 emissions during plastic microbial digestion contribute to global warming. Animals are exposed to plastic waste through ingestion and entanglement, with detrimental consequences. The 17 Sustainable Development Goals (SDGs) by the United

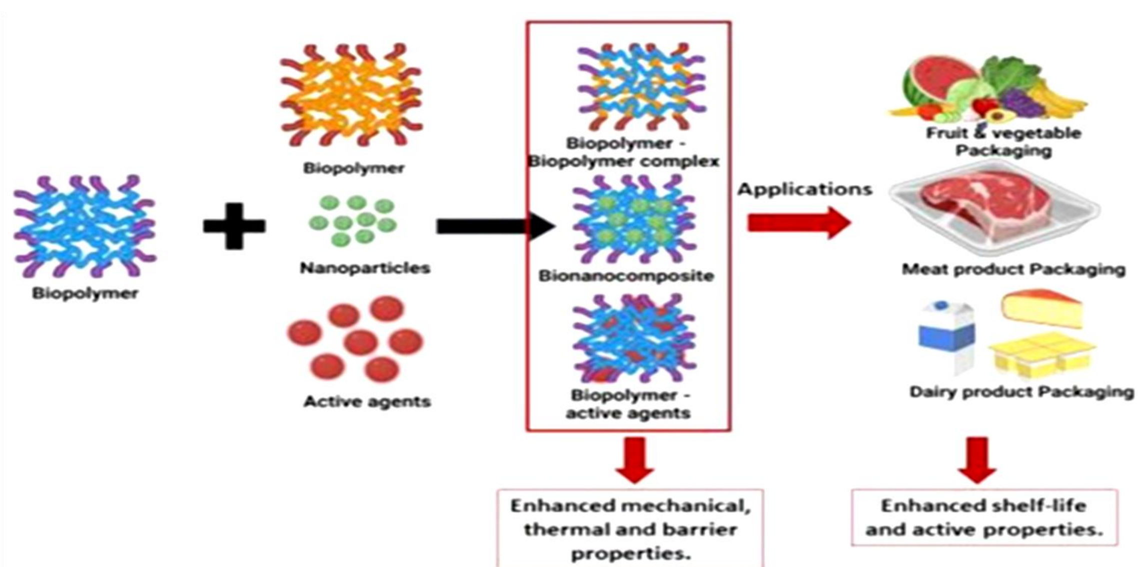

Fig.2. An overview of biopolymers in food packaging

Nations General Assembly in 2015 aim to promote sustainability, protect ecological life support systems, and reduce waste and pollution by 2030. The Basel Convention (1989), Rotterdam Convention (2004), and Stockholm Convention (2004) address the safe disposal and management of hazardous substances associated with plastic disposal. Legislation on global warming includes the United Nations Framework Convention on Climate Change (1992) (UNFCCC) and the Montreal Protocol (1987) (Reichert *et al.*, 2020).

4. Possible Solutions for Current Food Packaging Materials

Bio-nanocomposites, which consist of a bio-based polymer matrix and an organic/inorganic filler with at least one nanoscale material, are suitable as active and/or intelligent packaging materials due to their enhanced mechanical, thermal, barrier, antimicrobial, and antioxidant properties. These materials focus on extending shelf-life and reducing microbial growth in food products (Chaireh *et al.*, 2020).

5. Degradation Chemistry of Biopolymers

During biopolymer biodegradation, the polymers are first converted to monomers, and they are then mineralized. The mineralization of the organic material takes place by microorganisms (e.g., fungi, archaea, and bacteria) eventually resulting in carbon dioxide, water, and biomass. The reactions occurring during biopolymer biodegradation are as below:

Biodegradable polymers → CO_2+ H_2O + biomass (Lan *et al.*, 2021).

6. Advantages of Bioplastics

- **Reduced Carbon Footprint**: Bioplastics have a lower carbon footprint as they use renewable resources.
- **Biodegradability**: Many bioplastics can break down in natural environments, reducing plastic waste in oceans and landfills.
- **Non-Toxic**: Free from harmful chemicals, bioplastics are safer for food and medical packaging (Sid *et al.*, 2021).

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