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Research paper

Developing Eco-Friendly Biopolymers for Reducing Plastic Pollution

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Abstract

Polymers have many applications and have grown increasingly vital to everyday existence. The utilization of polyethylene has escalated twenty-five times over the previous fifty years and is projected to double in the subsequent years. Globally, around 325 million tons of polyethylene are generated annually. The manufacturing, utilization, and removal of polymers have become a chronic and significant hazard to the surroundings. The incorrect elimination of polymers contaminates the ecosystem, leading to the yearly demise of thousands of organisms and a decline in soil quality. Biodegradable plastics and Biopolymers (BP) derived from different forms of life may serve as substitutes for artificial polymers. BP may be derived from organic feedstock supplies, including carbohydrates, cellulose, pectin, collagen, and gelatin. All these BP have appropriate physicochemical, heat, and mechanical qualities that render them acceptable for natural and Eco-Friendly BP (EF-BP) manufacturing that mitigates plastic pollution (PP). The application of BP extends beyond bioplastics to include the sustainable manufacturing of many goods, including implantable devices, biological fuels, and pharmaceuticals. This study fully examines the components of BP, their extraction and purifying processes, and the factors that make them effective for environmental applications.

Keywords: *Polymers; Biopolymers; Plastic Pollution; Sustainability; Eco-friendly; Ecosystem.*

1. Introduction

Polymers are employed in numerous fields and are considered an essential component of modern civilization. The combined worldwide output of polymers during the previous 15 years is equivalent to half of the total polymers created since 1955. Worldwide plastic manufacturing is anticipated to rise in the coming years [1]. The projected worldwide plastic use over the subsequent 25 years is expected to exceed 750 metric tons in manufacturing levels. It is indisputable that our planet is inundated with substantial quantities of plastic garbage. Although polymers have been a fundamental component of our civilization for an extended period, the problem of PP is gaining prominence among populations worldwide [11].

Current traditional polymers are derived from petroleum products, including polyethylene, polyvinyl chlorides, and polymers, and their manufacture significantly uses natural gas, thus emitting elevated levels of greenhouse gases (GHG). Traditional plastics made from petroleum are environmentally resilient, rendering their manufacturing and removal a significant issue in several urban areas globally [3] [2]. Incorrect elimination of toxic plastic debris is a major contributor to ecological degradation and threatens life [6]. Traditional plastic garbage obstructs the infiltration and dispersion of oxygen and water into the ground, diminishing soil fertility, hindering the decomposition of biological material, and posing a threat to wildlife.

In the marine ecosystem, the discharge of plastic garbage may lead to the strangling and tangling of marine creatures. Standard polymers impose a significant financial burden on PP management [5]. The incineration of plastics may release hazardous substances, including dioxins. Currently, many types of polymers are employed for multiple applications, and the reuse of plastic trash is conducted via diverse procedures, making collecting and reusing plastic scraps more challenging. Recognizing this hazardous scenario, several countries worldwide observed Earth Day in 2019 under the slogan "Beat PP" [12].

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The recently established ecological rules, cultural apprehensions, and heightened ecological consciousness have catalyzed the quest for environmentally suitable goods. In this context, substituting recyclable petroleum-derived plastics with recyclable and sustainable resource-based polymers is of significant interest to policymakers and the plastics field. In this perspective, fostering public knowledge about BP is a commendable objective [7] [4]. This study examines several forms of BP and outlines their evolution and disposal methods. This article advocates for a rapid transition from conventional petroleum-based plastics to EF-BP.

Consequently, BP is generated by living organisms such as microbes, flora, and fauna or is artificially manufactured from organic precursors like glucose, cellulose, and lactate [13]. The extensive manufacturing and use of BP would save non-renewable petroleum-based reserves and mitigate associated ecological issues. Furthermore, it would provide benefits like decreased GHG emissions and enhanced waste disposal alternatives via chemical and biological regeneration [8].

Biodegradable properties might address the issues of worldwide PP EF-BP, which are generally biodegradable and may be put into the ground without adverse consequences since they disintegrate and disintegrate quickly [9]. Regrettably, some BP might leave harmful contaminants such as plastic pieces in the soil; for instance, certain categories of BP break down only at elevated temperatures in specialist composters. The uncontrolled discharge of recyclable polymers in the sea may result in the mortality of many marine creatures since the aquatic environment does not provide an appropriate setting for decomposition. Nonetheless, the proper application of collecting, separating, and recycling techniques would enhance the utilization of resources in the elimination of BP.

Furthermore, BP materials have superior durability and thermal endurance, resembling those of ordinary virgin plastics. BP is offered in several grades, exhibiting diverse characteristics [14]. BP goods are mostly employed for travel bags, super-absorbent materials in baby diapers, sewage treatment, diverse packaging uses, healthcare and dental implants, culinary and sanitary items, and agricultural composting. Although BP provides an affordable substitute to traditional plastics, their lack of cost-effectiveness has hindered the realization of their promise. Nonetheless, the increasing interest in environmental sustainability, the aspiration to diminish reliance on oil and gas, and the evolving regulations and perspectives in handling trash have enhanced the usability and accessibility of BP [10]. Moreover, buyer attitudes, consciousness, and research facilities are intensifying the global marketing of novel BP applications.

2. Developing EF-BP for reducing PP

Earth has around 1.25 million varieties of plants scattered across diverse geographical regions with varying environments. Certain trees and vegetation are cultivated for ornamental purposes, while others serve as sources of sustenance. Agricultural products comprise maize, rice, wheat, oats, cane sugar, and several vegetables, with numerous fruits. Annually, the world population eats a substantial quantity of nutrition, which serves as either an immediate or intermediate supply of vegetation. Substantial biological waste or agricultural leftovers persist after the collection of vegetable and fruit crops, which may be utilized as animal feed or sometimes incinerated on the fields. Likewise, food debris derived from organic feedstock is created in substantial quantities and is deemed worthless since it is now regarded as refuse or utilized for low-cost applications. Plant materials, including timber and non-edible components of vegetables and fruits, may be used sustainably to address polymer and ecological degradation by serving as raw materials for BP manufacture. Significant BPs, including carbohydrates, cellulose, and pectin, may be derived from various sources of plants. These polymers possess exceptional features that may be juxtaposed with contemporary artificial plastics, which have usurped the world's ecology and precipitated an ecological crisis. Several significant BP pertinent to bioplastic synthesis are examined.

2.1. Carbohydrates

Carbohydrates are mostly linked to plant-derived feedstock and are the most prevalent complex sugar. The basic component of this complex sugar is an elementary monomer, namely glucose, connected by α1-4 links. The fundamental composition of carbohydrates or starch is seen in Fig. 1.

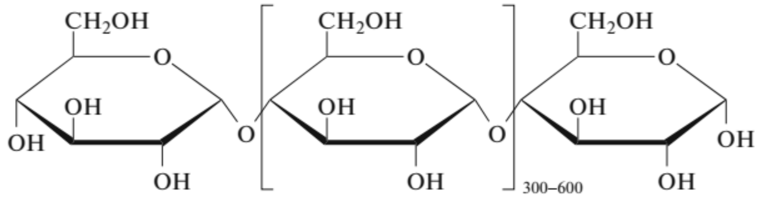

Fig. 1: The Fundamental Composition of Carbohydrate.

Glucose exists in two kinds: a straight-chain polymer called amylase and a branching polymer called amylopectin. Glucose has been utilized for ages for many applications, with paper-making being the most prevalent. Substantial amounts of carbohydrates have been utilized in the garment sector to enhance threads' endurance over knitting. Carbohydrates have been examined for EF-BP production as an organic byproduct of plant-derived feedstock.

The carbohydrates derived from tapioca chips, augmented with tiny cellulose crystals and dextrose as a plasticizing agent, enhanced the durability of the resulting BP. This work established that carbohydrates, as an EF-BP, are a viable choice for BP production. Starch-based BP sheets are both liquid and soil-degradable and are employed to create biodegradable, hard, and flexible plastic sheets. These BP sheets may function as gas shields and can be utilized in food packing with minor adjustments to their elastic properties by creating mixtures with other biodegradable polymers.

2.2. Cellulose

Cellulose is the predominant complex sugar found in the cell walls of plant tissues (Fig. 2). As a polymer composed of repetitive molecule units of sugar, it is frequently employed in paper manufacturing and as linen in apparel. Cellulite and triacetate constitute two BP obtained from cellulose. The resulting molecules produce a heat-resistant and stiff BP that is biodegradable in the environment. Lignin biomass resources, such as wood and rice husks, can be efficiently utilized as non-food materials for the EF advancement of BP. However, transforming this plant-based matter into basic leftovers for efficient utilization in BP investigation necessitates affordable methods for bioplastic progress.

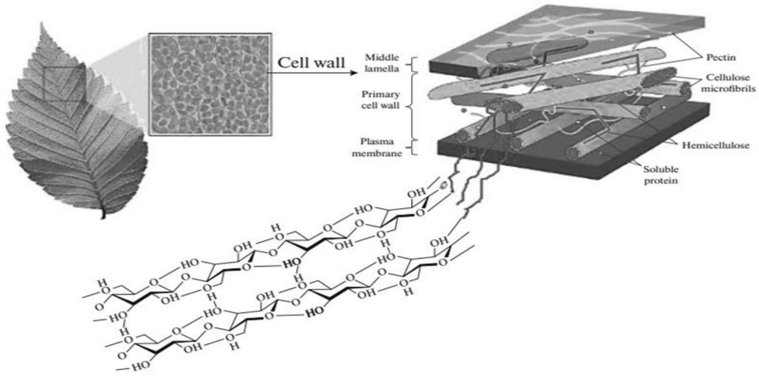

Fig. 2: Cellulose Found in the Cell Wall of Plant Tissues.

Approximately 45% of cellulose is found in the vacant crop group of the palm oil plant, and bioplastic manufacture from this cellulose has been examined. Cellulose lacks inherent qualities to serve as a viable biological plastic, yet its combination with plasticizing agents is crucial for BP's advancement. A bioplastic made from a cellulose and carbohydrate combination was synthesized employing solution circulating and transpiration, utilizing tapioca flour as the BP substrate and glycerin as the softener. The cellulose secondary chain has been oxygenated to reduce hydroxyl pairs and augment carboxyl groups for BP production. Subsequent studies may provide biological plastics derived from cellulose, which are suitable for producing grocery bags and food containers.

2.3. Pectin

Pectin is a polysaccharide mostly found in the cellular walls of plants on Earth. It is manufactured on a scale as a white to light brown powder, mostly derived from citrus peels. Pectin is the primary substance responsible for the hardening characteristics of fruit jellies and jams. A pectin-based BP sheet may be synthesized by incorporating 5 grams of pectin derived from banana peels into purified water and burning the solution to 50°C. The acquired sheet exhibits a width of 0.00398 cm, a water resilience of 65.12%, a breaking force of 12.007 MPa, and an extension of 61.12%. Fig. 3 illustrates the existence of pectin inside the plant cell wall of leaves.

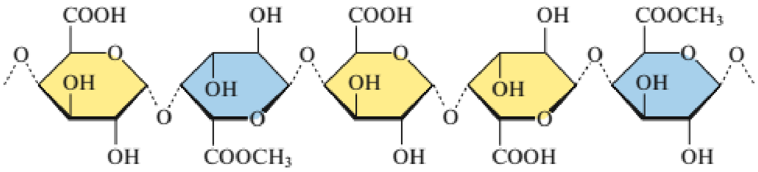

Fig. 3: Structure of Pectin.

2.4. Collagen

Collagen is a soluble and versatile peptide that is the primary substance in hair, wings, fingers, and animal limbs. Nearly 92% of chicken feathers consist of collagen. The poultry business produces around 75 million metric tons of meat yearly worldwide, indicating a substantial volume of chicken feathers generated as waste from this sector. Chicken feathers serve as feedstock for the long-term generation of BP, contributing to mitigating plastic emissions in the atmosphere. Collagen derived from chicken feathers applies to several microbiological domains, including BP sheets and strands. Bioplastic sheets produced with collagen at varying triglyceride percentages have distinct physicochemical features and breakdown rates. Biodegradable plastic sheets containing collagen with 1% glycerol are destroyed within 24 hours by applying a proteolytic enzyme. The degree of biological degradation fluctuates according to the levels of glycerol. Blending collagen with polymers like cellulose and starchy carbohydrates may enhance bioplastic characteristics.

The collagen-cellulose BP mix demonstrated superior biological and thermo-mechanical capabilities relative to the BP composed solely of collagen. In addition to chicken feathers, sheep wool is another source for acquiring outstanding collagen. The larger framework, including β-sheets and α-helices/coils, was altered mainly due to extraction by a moderate caustic oxidative technique; yet, substantial polymer portions of 14, 23, and 32 kDa were preserved, facilitating the creation of EF-BP sheets. Glycerol and sodium chloride sulfonate (SCS) were employed to plasticize the BP sheets, imparting varying hydrophilic characteristics to the BP.

2.5. Gelatin

Gelatin is a naturally produced polymer derived from animal hides, bones, and associated tissues. It has extensive uses across several industries, including cosmetics and pharmaceuticals. X-rays and photographs are processed with gelatin. EF sheets have been made for agricultural composting utilizing garbage gelatin and organic waste from biomass, including bags of sugarcane. The sheets were determined to be entirely biodegradable in the natural setting without exhibiting any harmful effects. Gelatin is an extensively used hydrocolloid in the food sector, renowned for its exceptional properties, which provide a broad spectrum of industrial uses. Gelatin derived from various sources has distinct peptide compositions, resulting in differing physicochemical qualities based on its origin. In the food business, gelatin-based BP sheets may serve as packaging components.

3. Conclusion

Biodegradable plastics and biopolymers (BP) from various living forms may be alternatives to synthetic polymers. Biopolymers may be derived from organic feedstock materials, including carbohydrates, cellulose, pectin, collagen, and gelatin. All these bioplastics possess suitable physicochemical, thermal, and mechanical properties that make them viable for producing natural and eco-friendly biopolymers (EF-BP) that reduce plastic pollution. BP transcends bioplastics, including the sustainable production of many products, such as implantable devices, biofuels, and medications. This paper comprehensively analyzes the constituents of BP, their extraction and purification methods, and the determinants of their efficacy in environmental applications.

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