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Synthesis of polymer from natural sources for more safe products

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Abstract

The environmental and economic burdens associated with petroleum-derived polymers necessitate the development of sustainable alternatives. This study investigates the synthesis and characterization of three bio-products derived from natural sources. Two biopolymers were synthesized from starch and gelatin, while the third was paper produced from banana peel. These materials were fabricated into children's toys and accessories. Characterization, including solubility, flame resistance, water absorption, and biodegradability assessments, demonstrated the potential of these bio-products as viable polymer replacements in diverse applications.

Key Words

Biopolymer, Starch, Gelatine, Banana peel

Introduction

The pervasive presence of synthetic polymers in modern life is undeniable. From packaging and textiles to medical devices and construction materials, these versatile materials have revolutionized numerous industries. However, the reliance on petroleum-based polymers has brought forth a cascade of environmental and health concerns. The depletion of fossil fuel reserves, the accumulation of non-biodegradable plastic waste, and the potential leaching of harmful additives from conventional polymers have ignited a pressing need for sustainable alternatives. This necessity has spurred a global shift towards the exploration and utilization of natural resources for polymer synthesis, aiming to create safer and more environmentally benign products. [Geyer et al., 2017, p.1700782] [Thompson et al., 2009, p.1973-1976]

The inherent limitations of traditional petroleum-derived polymers, such as their resistance to degradation and the associated microplastic pollution, have become increasingly apparent. Microplastics, tiny plastic particles resulting from the fragmentation of larger plastic debris, have infiltrated ecosystems worldwide, posing a significant threat to marine and terrestrial life. Moreover, the production of these polymers often involves the use of hazardous chemicals and energy-intensive processes, contributing to greenhouse gas emissions and environmental degradation. The release of toxic monomers and additives during polymer degradation or leaching from finished products further exacerbates the problem, raising concerns about human health risks. [Eriksen et al., 2014, p.111913] In contrast, natural polymers, derived from renewable resources like plants, animals, and microorganisms, offer a promising pathway towards sustainable material development. These biopolymers, including polysaccharides (e.g., starch, cellulose, chitin), proteins (e.g., collagen, silk), and lipids (e.g., vegetable oils, waxes), possess inherent biodegradability, biocompatibility, and low toxicity, making them ideal candidates for replacing conventional synthetic polymers in various applications. The utilization of these resources not only reduces our dependence on fossil fuels but also contributes to a circular economy by minimizing waste generation and promoting resource regeneration. [Wight et al., 2017, p.6634- 6647] [Rochman et al., 2013, p.1646- 1654]

The synthesis of polymers from natural sources involves a diverse range of chemical and biological techniques, tailored to the specific properties of the chosen biopolymer. These methods often focus on modifying the inherent properties of natural polymers to enhance their performance and expand their applicability. For example, chemical modifications like esterification, etherification, and grafting can improve the thermal stability, mechanical strength, and water resistance of polysaccharides. Similarly, enzymatic polymerization and microbial fermentation can be employed to produce biopolymers with controlled molecular weights and tailored functionalities. [Mohanty et al., 2002, p.19- 26]

The benefits of utilizing natural polymers extend beyond environmental sustainability (Figure 1). [Thakur et al., 2018, p.2207- 2262] The inherent biocompatibility of many biopolymers makes them particularly attractive for biomedical applications, such as drug delivery, tissue engineering, and wound healing. For instance, collagen-based scaffolds can promote tissue regeneration, while chitosan-based nanoparticles can deliver drugs to specific target sites. In the food industry, natural polymers can be used as edible packaging materials, thickening agents, and emulsifiers, enhancing food safety and shelf life. [Steven et al., 2002, p.187- 240] Furthermore, the use of bio-based polymers in consumer products, such as personal care items and household goods, can reduce exposure to potentially harmful synthetic chemicals. [Ratner et al., 2012, p.657-764]

However, the widespread adoption of biopolymers faces several challenges. The cost of production, the variability of natural resources, and the need for improved processing techniques are among the key obstacles that need to be addressed. Research efforts are focused on developing cost-effective and scalable production methods, optimizing the properties of biopolymers through chemical modification and blending, and exploring new sources of natural polymers. [Ebringerova' et Al., 2000, p.27-67]

Advancements in biotechnology, nanotechnology, and materials science are playing a crucial role in overcoming these challenges and accelerating the transition towards a bio-based economy. [Kobayashi et al., 2009, p.1- 17]

The exploration of diverse natural resources, including agricultural waste, forestry residues, and marine biomass, is vital for expanding the availability of biopolymers. [Dash et al., 2011, p.459- 494] Utilizing these underutilized resources not only reduces waste but also creates new economic opportunities for rural communities. Furthermore, the development of biorefineries, integrated facilities that convert biomass into a range of valuable products, is essential for maximizing the efficiency and sustainability of biopolymer production. [Bajpai et al., 2011, p.121-107667]

Based on the above, the synthesis of polymers from natural sources represents a paradigm shift in materials science, offering a sustainable and safer alternative to conventional petroleum-based polymers. [Philp et al., 2013, p.1-10] By harnessing the power of nature, we can create a new generation of materials that are not only environmentally friendly but also contribute to human well-being. [Clark et al., 2015, p183-190] This research aims to contribute to this burgeoning field by exploring methods for synthesizing biopolymers from specific natural sources and evaluating their potential applications in creating safer and more sustainable products. Through rigorous research and innovation, we can pave the way for a future where natural polymers play a central role in a circular and bio-based economy. [Demirbas et al., 2009, p.1- 45]

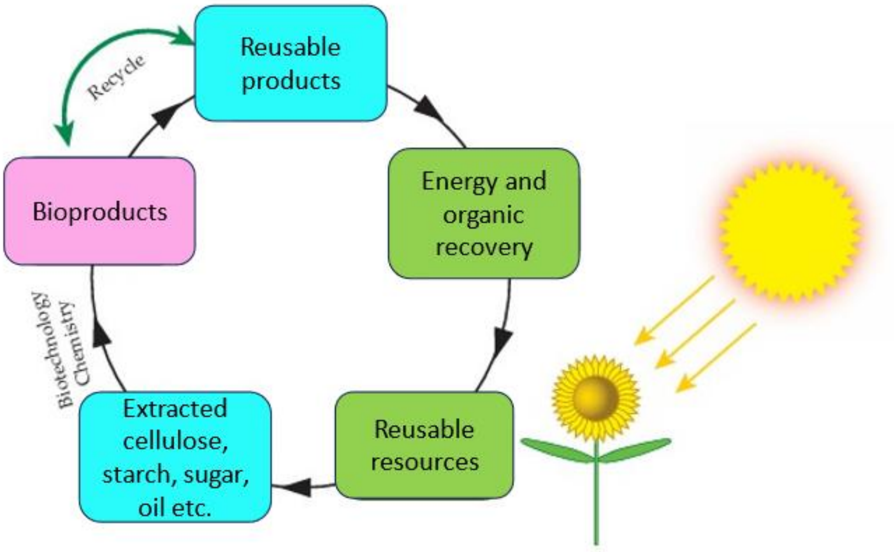

Figure 1. Bioproduct resource cycle

2. The Theoretical Framework

- **Biopolymers,** they are polymers produced by living organisms or derived from renewable biological resources. This distinguishes them from synthetic polymers derived from petrochemicals.
- **Biodegradability,** a key characteristic of many biopolymers is their biodegradability, meaning they can be broken down by microorganisms into natural substances. This is a significant environmental advantage.
- **Polymerization,** the fundamental process in biopolymer synthesis is polymerization, where monomers are linked together to form long polymer chains

  Synthesis from polysaccharides (e.g., Starch, Cellulose):

  o These are composed of sugar monomers.

  o Synthesis often involves extraction from plant sources and modification to improve processability.

  Gelatinization of starch, as seen in the example, is a process where starch granules are disrupted in the presence of heat and water, forming a viscous solution.

Synthesis from Proteins (e.g., Gelatin):

- These are composed of amino acid monomers.
- Gelatin, for example, is derived from collagen and its synthesis involves processes to break down the collagen structure.

- The addition of plasticizers, such as glycerin, is common to improve flexibility.

- **Banana peels,** they are a significant agricultural waste product, generated in large quantities globally. Utilizing them for production offers a way to reduce waste and create value. They contain valuable components, including:
    - Starch: A natural polymer that can be processed into bioplastics.
    - Cellulose: A fibrous material that can be used to create paper-like materials.

3. Methodology

3.1 Materials

The materials used were glycerine, gelatine, vinegar, starch, lemon juice, banana peel used papers hydrochloric acid, sodium hydroxide, ammonium hydroxide, acetic acid, ethanol, sulfuric acid and benzene, distilled water.

3.2 Measurements

Experimental work for this research was carried out in the chemical laboratory of Ain Shams University's Faculty of Education.

3.3 Synthesis Procedures

3.2.1 Starch-based Biopolymer Synthesis, S-polymer

A starch-based biopolymer was synthesized using a solution casting method. A mixture consisting of 1.5 g of starch, 1 mL of vinegar, and 0.5 mL of glycerine was prepared. This mixture was then added to 10 mL of distilled water and thoroughly mixed. The resulting suspension was subjected to gentle heating with continuous stirring until it reached boiling, inducing gelatinization of the starch. The resultant viscous solution (sludge) was subsequently poured into molds of desired shapes and allowed to dry completely at ambient temperature.

3.2.2 Gelatine-based Biopolymer Synthesis, G-polymer

A gelatine-based biopolymer was prepared by dissolving 23 g of gelatine in 800 mL of warm distilled water, ensuring thorough mixing. Subsequently, 30 mL of glycerine was added to the gelatine solution, and the mixture was heated with continuous stirring to ensure homogeneity. The resulting solution was then poured into molds of desired shapes and allowed to dry completely at ambient temperature.

3.2.3 Banana Peel-based Paper Synthesis, B-paper

A paper-like material was synthesized using banana peels and used paper. Initially, banana peels wer96/85e cut into small pieces and boiled in water for approximately 10 minutes to soften the fibres. Concurrently, used paper was processed into smaller fragments using a mixer grinder. The processed used paper was then added to the boiled banana peel mixture, and the combined materials were thoroughly mixed. The resulting pulp was poured into molds and allowed to harden, forming the paper-like material.

4. Results of Research

Two biopolymers were synthesized from starch and gelatine besides papers were made from banana peels for exploring ways to improve products that are environmentally friendly, safer, and also easy to biodegradable into natural materials. Starch-based biopolymer (**S-polymer**) was used to make teethers and toys for children to avoid the health risks resulting from the use of synthetic polymers as shown in Figure 2. Gelatin-based biopolymer (**G-polymer**) was used to make different accessories as shown in Figure 3. On the other hand, banana peel (**B-paper**) was used to make paper that was easily biodegradable and reusables shown in Figure 4. The prepared samples were characterized individually using solubility test, flame test, water absorption and biodegradability test.

Figure 2. Samples of the prepared **S-polymer**.

Figure 3. Samples of the prepared **G-polymer**.

Figure 4. Samples of the prepared **B-paper**.

4.1 Solubility test:

The physical properties and application suitability of three samples were assessed via solubility testing. This involved immersing small sample pieces in solvents of varying characteristics (water, hydrochloric acid, sodium hydroxide, ammonium hydroxide, acetic acid, ethanol, sulfuric acid and benzene) for 10 minutes, thereby determining their susceptibility to solvent-induced deterioration. The quantified solubility results are detailed in Table 1.

Table 1: The solubility test of the prepared bio-products.

Solvent	S-polymer	G-polymer	B-paper
Cold water	Insoluble	soluble	soluble
Warm water	Partially soluble	soluble	soluble
HCl (0.1 M)	Insoluble	soluble	Insoluble with weak effervescence
H_2SO_4 (0.1 M)	Insoluble	soluble	Insoluble with weak effervescence
CH_3COOH (0.1 M)	Insoluble	Partially soluble with turbidity	Insoluble
NH_4OH (0.1 M)	Partially soluble with turbidity	Soluble	Insoluble
NaOH (0.1 M)	Soluble	Soluble	Partially soluble with turbidity
Ethanol	Insoluble	Insoluble	Insoluble
Benzene	Insoluble	Insoluble	Insoluble

4.2. Flame test

Flame tests were performed on three samples of equivalent mass as shown in Table 2. The starch-based biopolymer (**S-polymer**) exhibited the highest resistance to combustion, evidenced by the extended duration required for ignition and subsequent burning.

Table 2: The flame test of the prepared bio-products.

Substance	S-polymer	G-polymer	B-paper
Combustion time	45 sec.	22 sec.	21 sec.

4.3. Water absorption

The water absorption test was conducted to quantify the hygroscopic properties and assess the dimensional stability of bioplastic samples under aqueous conditions. Samples were immersed distilled water for a period of two hours, and the subsequent mass increase was measured to determine the extent of water uptake. This methodology provides insight into the material's susceptibility to water infiltration and potential for volumetric expansion. The starch-based biopolymer (**S-polymer**) exhibited the lowest water absorption, indicating superior resistance to moisture uptake, as detailed in Table 3.

Table 3: Water absorption property of the prepared bio-products.

Sample	Initial Wt. (gm)	Final Wt. (gm)	Percentage Weight gain %
S-polymer	0.64	1.12	0.48
G-polymer	0.64	2.74	2.10
B-paper	0.64	2.70	2.06

4.4. Biodegradability Test

To ascertain the environmental compatibility of bio-products, biodegradability tests were performed, quantifying degradation rates and ecological assimilation. To quantify the biodegradability of three bio-product samples of equal initial weight (W1), a five-day soil burial test was conducted. The samples were placed in cups with damp garden soil at room temperature, maintained in a moist environment, then retrieved, washed, dried, and re-weighed (W2). The biodegradability was subsequently calculated using the next formula, and the results were recorded in Table 4, providing a measure of the samples' decomposition under soil conditions.

$$\textbf{Biodegradability (\%)} = \left(\frac{W1 - W2}{W1} \right)$$

Table 4: Biodegradability features of the prepared bio-products.

Sample	Initial Wt. (gm)	Final Wt. (gm)	Weight loss (gm)	Percentage %
S-polymer	0.43	0.36	0.07	16.27 %
G-polymer	0.43	0.31	0.12	27.90 %
B-paper	0.43	0.00	0.43	100 %

The biodegradability assays revealed significant differences in degradation rates among the tested materials. **S-polymer** exhibited the lowest mass loss and corresponding percentage of biodegradability, indicating limited decomposition under the experimental conditions. Conversely, **B-paper** demonstrated the highest mass loss, with complete degradation observed, suggesting rapid decomposition within the soil matrix.

5. Conclusion

This study successfully demonstrated the feasibility of synthesizing and characterizing three bio-products derived from starch, gelatin, and banana peel as sustainable alternatives to petroleum-derived polymers. The fabrication of children's toys and accessories, coupled with comprehensive characterization of their solubility, flame resistance, water absorption, and biodegradability, highlights their potential for diverse applications. These findings contribute to the growing body of research aimed at mitigating the environmental and economic burdens associated with traditional plastics, paving the way for further exploration and implementation of bio-based materials.

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