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Development Analysis & Enhancement of Eco-Friendly Plastic Derived From Potato Starch

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Abstract

Plastic pollution has emerged as a significant global environmental issue due to the widespread use of non-biodegradable plastics made from petroleum in sectors such as packaging, agriculture, healthcare, and industry. Traditional plastics can remain in ecosystems for hundreds of years, leading to soil degradation, water pollution, the buildup of microplastics, and negative impacts on both human and animal health. To address these issues, biodegradable plastics made from renewable resources have been developed as sustainable alternatives. Among these, starch-based bioplastics, especially those made from potato starch, have attracted considerable interest due to their biodegradability, cost-effectiveness, abundance, and environmentally friendly characteristics. This review paper examines the environmental impact of traditional plastics, the development and importance of biodegradable polymers, and the use of starch as a viable raw material for producing bioplastics. The study delves into the physicochemical characteristics of potato starch, techniques for creating thermoplastic starch, and the role of plasticizers like glycerol. It also explores recent progress in enhancing mechanical strength, water resistance, and industrial use. Furthermore, it discusses the biodegradation processes, practical uses, challenges, and future outlook of starch based biodegradable plastics.

KEYWORDS: Biodegradable plastics, Thermoplastic starch, Sustainable materials, Renewable resources, Environmental sustainability, etc.

1. Introduction

Plastics have become essential in contemporary society because of their outstanding physicochemical characteristics, including durability, light weight, flexibility, and cost efficiency. Since their widespread commercialization began in the mid-20th century, plastics have transformed numerous industries such as packaging, healthcare, agriculture, electronics, and transportation (Yu & Flury, 2024; Geyer, Jambeck, & Law, 2023). Their adaptability enables them to be shaped into various forms, making them crucial for both household and industrial uses (Andrady, 2022).

The swift advancement of industrialization, urbanization, and population expansion has greatly amplified the worldwide need for plastic materials. Recent estimates indicate that global plastic production has surpassed 390 million tonnes each year, with a large portion allocated to single use purposes (Plastics Europe, 2024). Although this increase has spurred economic growth, it has also led to significant environmental issues (OECD, 2022).

Despite their extensive usefulness, traditional plastics pose significant environmental issues due to their inability to biodegrade. These substances remain in the ecosystem for centuries, causing prolonged ecological harm (Liang et al., 2024). Most traditional plastics are produced from nonrenewable petrochemical sources like crude oil and natural gas and are made up of polymers such as polypropylene (PP), polystyrene (PS), polyethylene (PE), which do not easily decompose naturally (Andrady, 2022). Poor disposal methods, including landfilling, open dumping, and littering, have led to the widespread accumulation of plastic waste in both land and water environments. Plastic waste is now frequently discovered in oceans, rivers, soils, and even in isolated areas (Yu & Flury, 2024; UNEP, 2023). Marine environments are especially impacted, as millions of tons of plastic waste are dumped into oceans each year, posing significant dangers to marine organisms (Liang et al., 2024). The enduring presence of plastic waste disrupts ecological equilibrium and biodiversity by hindering natural processes like nutrient cycling and habitat creation (OECD, 2022).

Over time, larger pieces of plastic break down into smaller fragments due to environmental influences like ultraviolet light, temperature changes, and physical wear, leading to the formation of microplastics, which are particles smaller than 5 mm (Liang et al., 2024).These microplastics have become widespread in soil, water, and air, making them a common environmental pollutant.

Research has found microplastics in drinking water, food items, and even within human tissues (Leslie et al., 2022; WHO, 2023). These particles can serve as carriers for harmful chemicals, heavy metals, and disease-causing microorganisms, which may lead to inflammation, oxidative stress and damage to cells in humans (Prata et al., 2023).

Plastic waste management methods like incineration play a major role in air pollution by emitting harmful gases such as carbon monoxide, hydrogen chloride, dioxins, and furans (Verma et al., 2023).

These pollutants are associated with respiratory illnesses and a heightened risk of cancer (WHO, 2023). The creation and disposal of plastics also lead to greenhouse gas emissions, which exacerbate climate change (Zheng & Suh, 2023). These environmental and health issues have led to an urgent demand for sustainable and environmentally friendly alternatives to traditional plastics (UNEP, 2023).

The study illustrates that employing straightforward and cost-effective production techniques boosts the practicality of using these materials locally. Nonetheless, for applications on an industrial scale, enhancements in mechanical strength, water resistance, and durability are required. Recent progress in polymer blending, nanocomposites, and chemical modification has yielded encouraging outcomes in improving the performance of starch-based bioplastics (Zhang et al., 2025). Furthermore, adding natural substances like antimicrobial agents can broaden the functionality of these materials, making them apt for advanced packaging uses.

2. Raw Material & Pre Treatment

The materials needed for the experiment were sourced from local vendors and standard lab suppliers. Fresh potatoes were chosen for their consistent size, firmness, and lack of visible flaws such as mold, sprouting, or rot. The diced potatoes were processed right away to avoid enzymatic browning, which could negatively impact the appearance and quality of the starch obtained. This step is essential to avoid contamination in later processing stages the potatoes were manually peeled to remove the outer skin after cleaning which contains pigments, phenolic compounds, and fibrous materials that may interfere with starch purity and affect the quality of the final bioplastic (Thakur et al., 2022).

2.1 Starch Extraction Process- Potato pieces were chopped and then blended with a specific amount of distilled water using a laboratory blender to create uniform slurry. This blending action breaks open the cell walls, allowing starch granules to be released into the water (Tester et al., 2024). The resulting mixture was then passed through a muslin cloth or fine sieve to separate the solid fibrous material from the liquid starch suspension as shown in **Fig. 1**. The filtrate comprised suspended starch granules, soluble proteins, and other minor constituents (Hoover, 2021).

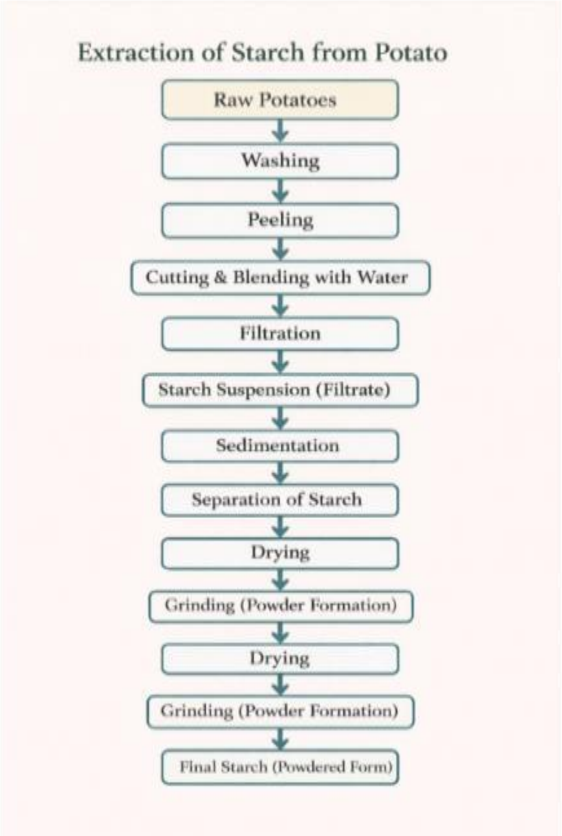

Figure 1: Flow Chart of Starch Preparation

2.2 Thermal Processing and Gelatinization- The polymer blend was heated in a controlled manner using a hot plate, with the temperature kept between 70°C and 90°C, while stirring was maintained continuously. This heating process triggers the gelatinization of starch, a crucial step in creating thermoplastic starch that greatly affects the material's final properties (Gurunathan et al., 2025; Anitha et al., 2024). During gelatinization, starch granules take in water and expand, causing their crystalline structure to break down. This leads to the release of amylose and amylopectin molecules into the surrounding environment, resulting in the formation of a thick gel (Zhang et al., 2024).

2.3 Casting of Bioplastic Film- Once gelatinization was complete, the hot, thick polymer gel was promptly moved to the casting phase. This stage is crucial for establishing the thickness, consistency, clarity, and mechanical characteristics of the resulting bioplastic film (Gurunathan et al., 2025; Nguyen et al., 2024). While still in a semi-liquid form, the gel was meticulously poured onto a clean, flat, non-stick surface like a glass plate, plastic tray, or aluminum foil. Utilizing a smooth casting surface facilitated the easy removal of the dried film and minimized surface imperfections (Anitha et al., 2024).

2.4 Drying Process and Film Formation- The bioplastic films were subjected to a controlled drying process to eliminate moisture and establish a solid polymer structure. This drying phase is vital as it greatly affects the mechanical, physical, and structural characteristics of the final product. The films were left to dry in a laboratory setting at temperatures between 25–30°C for 24–48 hours. During this period, the water in the gel slowly evaporated, allowing the polymer chains to consolidate into a continuous film. Controlled, slow drying is crucial to avoid defects like cracking, warping, and uneven surfaces. If water evaporates too quickly, it can create internal stress within the film, leading to deformation or brittleness (Thakur et al., 2022).

2.5 Characterization and Testing of Bioplastic- The starch-based bioplastic films that were prepared underwent a variety of characterization and evaluation tests to examine their physical, mechanical, and environmental properties. These tests aimed to evaluate whether the developed material could serve as a viable alternative to traditional plastics. The evaluation process encompassed tests for biodegradability, assessments of mechanical properties, analyses of water sensitivity, and other physical characterizations. All tests were performed in controlled laboratory settings, with observations systematically recorded for precise analysis (Thakur et al., 2022; Kumar et al., 2023).

3. Preparation, Characterization and Biodegradation of Bioplastics

Bioplastics sourced from renewable materials have become a promising alternative to traditional plastics due to their environmentally friendly and biodegradable properties. Starch-based bioplastics, in particular, have been the focus of extensive research because they are readily available, cost-effective, and easy to process. Researchers have explored the development of these bioplastics by incorporating various natural polymers and plasticizers to enhance their physical and mechanical properties. Beyond the synthesis process, significant efforts have been made to characterize these bioplastics, assessing their structural, mechanical, and water-related properties. Moreover, understanding their biodegradation behavior is crucial for evaluating their environmental impact and practical applications. This section provides an overview of the common methods used in the preparation, characterization, and biodegradation of starch-based bioplastics.

3.1 Formation of Biodegradable Plastic (Bioplastic)- Biodegradable plastic was effectively created using potato starch as the main ingredient through a controlled process of heating and casting. The combination of starch, distilled water, glycerol, and acetic acid was heated until it gelatinized, forming a thick gel as shown in **Fig 2**. After drying the gel transformed into a thin seamless plastic film. The resulting bioplastic sheet was smooth, even, and semitransparent, with a surface free of cracks and air bubbles, indicating proper mixing and controlled heating during its creation. The plastic showed moderate flexibility, allowing it to bend without breaking.

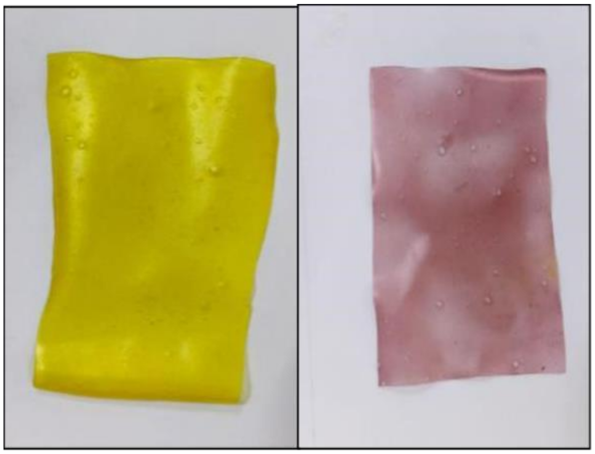

Figure 2: Prepared Biodegradable Plastic Film

3.2 Evaluation of Biodegradation Efficiency of Bioplastic- The biodegradability of the produced plastic was evaluated using the soil burial method. The samples were placed in damp soil and monitored over a span of five days. Degradation was tracked by observing visual changes such as softening, cracking, and breaking apart. Initially, no notable changes were detected; however, within 24 hours, the plastic started to lose its stiffness. By the third day, noticeable cracks and fragmentation were evident. By the fifth day, degradation reached approximately 90–95%, as detailed in **Table 1.**

Table 1: Degradation of bioplastic vs Commercial Plastic

	Biodegradable Plastic (%)	**Commercial Plastic (%)**
0	0	0
1	20	0
2	40	0
3	65	0
4	80	0
5	95	0

The graphical depiction shows a consistent rise in the degradation percentage for biodegradable plastic, whereas commercial plastic exhibits no degradation, underscoring the eco-friendly nature of starch-based plastic as demonstrated in **Fig. 3**.

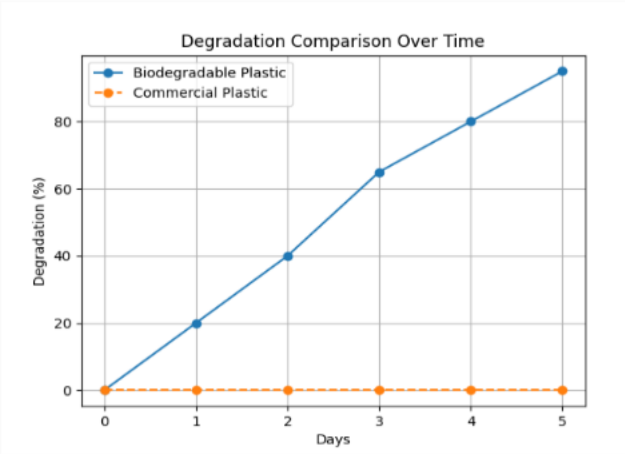

Figure 3: Degradation Comparison Graph

3.3 Estimation of Water Solubility in Bioplastic- One major limitation of the developed bioplastic is its inability to resist water. The material tends to absorb moisture significantly, becoming soft and sticky when exposed to water. This issue is primarily due to the starch's hydrophilic nature, which readily forms hydrogen bonds with water molecules. Recent research supports the notion that moisture sensitivity is a significant limitation of starch-based bioplastics, restricting their use in damp or wet conditions (Sobeih et al., 2025).

The hydrophilic nature of starch not only impacts water resistance but also affects the material's overall durability and stability. As moisture is taken in, the polymer matrix loses its strength, leading to a reduction in mechanical durability as shown in **Fig 4**.

This limitation underscores the necessity for further modification techniques, such as blending or cross-linking, to enhance water resistance.

Figure 4: Water Solubility Test

This research highlights that although bioplastics have not yet fully replaced traditional petroleum based plastics, they are an important and essential step toward developing sustainable materials. The growing environmental issues related to plastic pollution, such as their non-biodegradable nature, accumulation in ecosystems, and harmful impacts on wildlife and human health, necessitate the search for alternative materials. In this regard, biodegradable plastics made from natural sources like starch present a promising solution.

This research reveals that biodegradable plastics made from starch can be effectively created using straightforward and economical techniques. As a renewable and abundantly available natural polymer, starch is an ideal raw material for producing bioplastics. However, the research highlights some intrinsic limitations of starch, such as its weak mechanical properties, tendency to be brittle and high vulnerability to moisture. These limitations hinder the use of starch-based plastics in applications that demand durability and resistance to environmental factors.

The research highlights the financial difficulties linked to the mass production of biodegradable plastics. The results of this study underscore the critical need for sustainable strategies to address the worldwide plastic pollution issue. Despite ongoing challenges such as material constraints, economic viability, and infrastructure deficiencies, progress in this area continues to inspire optimism for a more sustainable future. Through relentless research and innovation, biodegradable plastics have the potential to significantly mitigate environmental pollution and contribute to a cleaner, greener planet.

4. Conclusion

The current research illustrates that bioplastics derived from potato starch offer a viable and eco-friendly alternative to traditional plastics made from petroleum. The growing environmental issues linked to plastic pollution, such as their non-biodegradable nature, accumulation in ecosystems, and harmful effects on living beings, underscore the need for sustainable materials. In this regard, the successful creation and assessment of starch-based bioplastics underscore their promise as renewable and biodegradable replacements.

The research further highlights the significance of employing renewable resources like potato starch, which fosters sustainable resource management and aligns with the principles of a circular economy. Due to their biodegradable properties, these materials are particularly well-suited for temporary uses such as packaging, disposable items, and agricultural films. While it may not be feasible to completely replace traditional plastics right away, targeted partial substitutions can significantly mitigate environmental pollution. Future investigations should aim to enhance the performance of starch-based bioplastics, focusing on improving their strength, durability, and resistance to water. Another crucial area is the development of bio-based plasticizers and environmentally friendly additives, which can boost material efficiency while ensuring sustainability.

Additionally, there is a necessity to create cost-effective and scalable production methods, like refined extrusion and injection molding processes, to support industrial implementation.

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