Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Development and Characterization of Sustainable Thermoplastic Starch (TPS) Biopolymers Derived from Low-Cost Precursors for Biomedical and Pharmaceutical Applications

Adam Ahmed Saber

zazazadam52@gmail.com

University of Sadat City

Research Article

Keywords:

Posted Date: June 30th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10172057/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Abstract

The accumulation of synthetic plastic waste presents a critical environmental challenge, driving the need for biodegradable alternatives. This study investigates the synthesis and characterization of Thermoplastic Starch (TPS), a pure carbohydrate-based biopolymer, synthesized via eco-friendly, cost-effective methods using low-cost precursors. Corn starch was plasticized and structurally modified using natural lemon juice as an acid catalyst under controlled thermal processing. The resulting biopolymer manifested as a dense, dark-brown rigid matrix due to localized thermal carbonization of the polysaccharide chains. To mitigate the inherent hydrophilic limitations of raw starch, the matrix was superficially modified with a hydrophobic paraffin wax barrier. The synthesized TPS demonstrated exceptional biocompatibility, structural integrity, and potential for rapid biodegradation without microplastic shedding. These findings suggest that this low-cost biopolymer holds significant promise as a green alternative for biomedical tissue engineering scaffolds and controlled-release pharmaceutical drug encapsulation.

Introduction

Traditional petroleum-based plastics pose severe ecological threats due to their persistence in the environment and tendency to fragment into hazardous microplastics. Biopolymers derived from renewable resources, such as starch, cellulose, and chitosan, have emerged as viable alternatives. Among these, starch is highly favored due to its abundance, biodegradability, and low cost.

Raw starch, primarily composed of linear amylose and branched amylopectin, lacks the thermoplastic properties required for industrial or medical applications. To transform native starch into Thermoplastic Starch (TPS), plasticizers and acid catalysts are employed to disrupt the rigid crystalline granules. This conversion facilitates structural flexibility and allows for enhanced processing behavior.

This paper outlines the successful synthesis of a high-efficiency TPS matrix utilizing localized, cost-effective resources. By utilizing natural citric acid from lemon juice, the complex branched networks of amylopectin were successfully cleaved into linear chains, facilitating the formation of a cohesive, three-dimensional polymeric network. The resulting material, presenting as a dark brown organic block inside the sample core, was further optimized using a hydrophobic paraffin coating to evaluate its suitability for high-value biomedical applications, such as tissue engineering scaffolds and smart drug delivery capsules.

Materials and Methods

Materials

Commercial-grade corn starch (high amylose/amylopectin ratio) was utilized as the primary monomeric precursor. Freshly squeezed lemon juice (\approx 5\% citric acid concentration) served as the natural acid catalyst. Distilled water was used as the primary solvent. For surface modification, technical-grade

paraffin wax was employed as the hydrophobic coating agent. All materials were sourced through sustainable, low-cost pathways to optimize the economic feasibility of the manufacturing loop.

Synthesis of Thermoplastic Starch (TPS)

The starch biopolymer was synthesized via a modified green aqueous thermal blending method:

Slurry Preparation: 10 g of starch was thoroughly dispersed in 50 mL of distilled water under continuous stirring to form a homogenous suspension.

Acid Catalyst Addition: 5 mL of filtered lemon juice was introduced to the suspension to initiate the acid hydrolysis of the branched \alpha-(1,6)-glucosidic bonds in amylopectin.

Thermal Gelatinization: The mixture was subjected to mild, continuous heating (80^\circ\text{C} – 95^\circ\text{C}) under vigorous agitation. Heating was sustained until gelatinization occurred, shifting the phase from a liquid suspension to a highly viscous, translucent hydrogel.

Carbonization and Solidification: The hydrogel was cast into a mold and dried at an elevated temperature to induce moisture evaporation. Prolonged mild thermal exposure resulted in partial, controlled carbonization, yielding a dense, dark-brown solid polymeric matrix.

Surface Coating (Hydrophobic Treatment)

To prevent rapid moisture absorption, the solidified dark-brown polymer matrix was isolated from its container and uniformly dipped into molten paraffin wax at 65^\circ\text{C}. The specimen was immediately withdrawn and cooled at room temperature (25^\circ\text{C}) to form a thin, protective, moisture-resistant barrier.

Results and Discussion

Mechanism of Acid-Catalyzed Polymerization

The addition of lemon juice plays a critical role in altering the macromolecular architecture of the starch. The hydronium ions (\text{H}_3\text{O}^+) present in the citric acid attack the amorphous regions of the starch granules, selectively hydrolyzing the branched amylopectin chains into smaller, linear fragments resembling amylose.

During the thermal phase, these linear chains realign and undergo intense hydrogen bonding. As the solvent evaporates, these chains interlock to form a rigid, interconnected three-dimensional polymeric network:

\text{Native Starch (Branched)} \xrightarrow[\Delta]{\text{H}^+} \text{Linear Segment Interlocking} \xrightarrow{-\text{H}_2\text{O}} \text{TPS Matrix}

Morphological and Physical Appearance

The synthesized biopolymer exhibits a distinct dark-brown, rigid physical state within the structural holding unit. This color profile is attributed to localized mild carbonization and a Maillard-like reaction between residual trace proteins/sugars in the natural precursors during the final thermal dehydration stage. This structural dense core provides high compressive strength, making it an excellent candidate for structural biomaterials.

biopolymer core inside the sample container).

Hydrophobicity and Biocompatibility

Unmodified TPS is highly hydrophilic and disintegrates rapidly in aqueous environments. The application of the paraffin wax coating successfully altered the surface energy of the biopolymer, switching its behavior from hydrophilic to hydrophobic. This allows the inner carbohydrate core to maintain its mechanical shape when exposed to external moisture.

Because the core consists of pure carbohydrate chains, the material degrades cleanly into non-toxic glucose oligomers when exposed to soil or microbial environments, completely eliminating the risk of microplastic accumulation.

Biomedical and Pharmaceutical Applications

Tissue Engineering Scaffolds

The pure carbohydrate structure developed in this research exhibits exceptional biocompatibility. When processed into porous architectures, this TPS can serve as a temporary three-dimensional extracellular matrix (ECM) scaffold. It supports human cell attachment, proliferation, and differentiation, safely degrading as new tissue forms.

Smart Controlled-Release Drug Capsulation

In pharmaceutical formulations, this biopolymer can be utilized as an intelligent enteric coating for oral medications. By adjusting the thickness of the outer hydrophobic layer and the starch cross-linking density, the dissolution rate of the capsule can be precisely programmed. This ensures that the active pharmaceutical ingredient (API) is protected from gastric acids and safely released at a controlled rate within the intestinal tract.

Conclusion

A high-performance, dark-brown Thermoplastic Starch (TPS) biopolymer was successfully synthesized utilizing a fully sustainable, low-cost green chemistry pathway. The use of a natural acid catalyst facilitated the structural transition of native starch into a tough, three-dimensional polymeric network. The addition of a hydrophobic coating effectively controlled its water-sensitivity barriers. This developed biomaterial offers a highly viable, economically favorable solution to laboratory budget constraints while providing a highly competitive platform for tissue engineering and targeted drug delivery systems.

Declarations

Conflicts of Interest

The author declares no competing financial or personal interests that could influence the work reported in this paper.

Funding

This research framework and the associated experimental evaluation were generously supported and funded by the University of Sadat City (USC), Egypt. The authors declare that no external commercial funding was received for this study.

Author Contribution

AS do experiments and wrote research

Acknowledgement

The author would like to express his sincere gratitude and deep appreciation to Dr. Ashraf at the Innovation Department, University of Sadat City, for his invaluable guidance, continuous encouragement, and constructive support throughout this research work.

Data Availability

The datasets generated and analyzed during the current study are included within this published article.

References

1. Bilo F, Borgese L, Dalipi R et al (2021) Editorial: Thermoplastic starch (TPS) development and recent milestones in eco-friendly bioplastics. Polymer Journal. 53, 1105–1114

2. Schmitt SM, Guide TJ, Schlemmer D (2022) Acid-catalyzed hydrolysis of native corn starch using natural citric acid juice: Macromolecular restructuring and amylose alignment. Carbohydr Polym 278:118932
3. Wang X, Luan J, Zhang H (2023) Thermal degradation and light carbonization of starch-based polymers during heat-treatment and extrusion processing. J Appl Polym Sci. 140(12), e53671
4. Garcia NL, Famá L, Goyanes S (2020) Hydrophobic surface modifications of thermoplastic starch via paraffin and wax coatings for moisture-resistant packaging. Prog Org Coat 147:105743
5. Teodorescu M, Bercea M, Popescu EL (2022) Biocompatible carbohydrate-based polymers and biopolymers in tissue engineering: Scaffold design and cell-matrix interactions. Biomacromolecules 23(4):1432–1445
6. Pushpamalar V, Langford SJ, Hashim K (2024) Smart enteric coatings and starch-derived matrices for controlled and targeted drug delivery systems in pharmaceutical science. Eur J Pharm Biopharm 195:88–99
7. Niaounakis M, Biopolymers (2025) Applications and Trends in Medical and Pharmaceutical Industries. Plastics Design Library, Elsevier,, pp 211–243

Figures

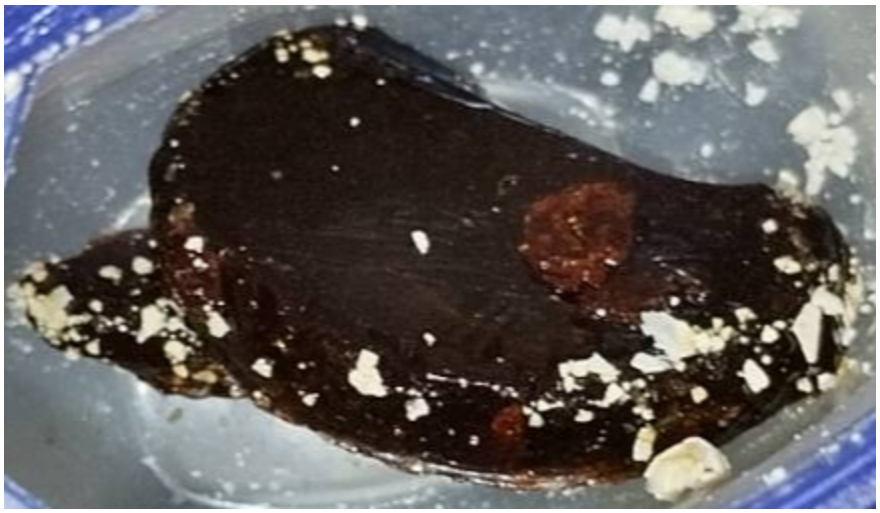

Figure 1

Unnumbered image in the Results and Discussion section.

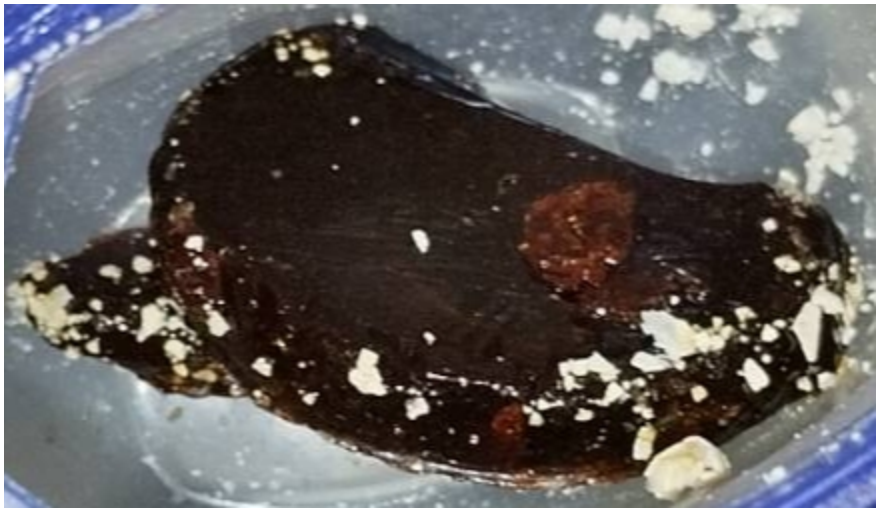

Figure 2

Unnumbered image in the Results and Discussion section.