

Synthesis and characterization of sustainable bioplastics from cotton agricultural waste

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ABSTRACT

Study objective: To synthesize and characterize a biodegradable plastic alternative utilizing cellulose extracted from discarded cotton agricultural waste, addressing both local agricultural byproducts and global plastic pollution.

Design: Experimental synthesis involving alkaline treatment for cellulose extraction, followed by plasticization using glycerol.

Setting: Presidential School in Samarkand chemistry laboratory.

Participants: Not applicable.

Interventions: Cotton waste was treated with NaOH to extract cellulose, which was then blended with varying concentrations of glycerol (10%, 20%, 30% w/w) and cast into thin films.

Main outcome measure(s): Tensile strength (MPa), elongation at break (%), and soil biodegradability over 30 days.

Results: The bioplastic film with 20% glycerol exhibited the optimal balance of mechanical properties, yielding a tensile strength of 15.2 MPa and 34% elongation at break. Soil degradation tests showed a 68% mass loss within 30 days.

Conclusions: Cotton agricultural waste is a viable and highly effective feedstock for bioplastic production. The resulting films offer competitive mechanical properties and rapid environmental degradation, presenting a sustainable circular economy model for the region.

Keywords:

Bioplastics; Cellulose extraction; Cotton waste; Circular economy; Glycerol plasticizer.

Introduction

The proliferation of petroleum-based plastics has led to an unprecedented global environmental crisis. Traditional synthetic polymers, primarily derived from petrochemical sources, are characterized by highly stable covalent bonds that render them exceptionally durable and resistant to natural environmental degradation processes.¹ Consequently, the accumulation of macro- and microplastics in terrestrial and aquatic ecosystems poses severe threats to biodiversity, soil health, and human food chains. In response to this ecological imperative, the development of bioplastics—polymers derived from renewable biomass sources—has emerged as a critical and rapidly advancing area of materials science.

In regions characterized by intensive agricultural sectors, such as Uzbekistan, farming generates substantial lignocellulosic biomass waste. Cotton farming, in particular, leaves behind vast quantities of stalks, linters, and low-quality fibers in the fields post-harvest. Historically, the default management strategy for this agricultural residue has been open-field burning or leaving it to decompose organically. Both practices are environmentally detrimental, releasing significant volumes of carbon dioxide, methane, and particulate matter into the atmosphere, thereby exacerbating climate change. However, cotton biomass is naturally abundant in cellulose ($C_6H_{10}O_5$)_n, a linear polysaccharide consisting of a linear chain of several hundred to many thousands of $\beta(1 \rightarrow 4)$ linked D-glucose units. This high cellulose content makes cotton agricultural waste an exceptional, yet vastly underutilized, precursor for biopolymer synthesis.²

The objective of this study is to synthesize a sustainable, functional bioplastic film by extracting and utilizing cellulose derived from local cotton waste. Pure cellulose films, while highly biodegradable, suffer from extensive inter- and intramolecular hydrogen bonding, which

makes them inherently brittle and unsuitable for most commercial packaging applications. To overcome this mechanical limitation, this research utilizes glycerol, a highly effective and eco-friendly polyol, as a plasticizer.³ Glycerol molecules interpose themselves between the cellulose polymer chains, disrupting the hydrogen bonding network, increasing free volume, and significantly enhancing the flexibility of the resulting material. This research not only proposes a viable, mechanically sound alternative to single-use synthetic plastics but also champions a closed-loop circular economy model that upcycles low-value agricultural waste into high-value sustainable materials.

Materials and methods

Cotton waste samples were collected locally in the Samarqand Region to ensure regional relevance. Sodium hydroxide (NaOH, 98% purity), hydrogen peroxide (H_2O_2 , 30% v/v), glacial acetic acid (CH_3COOH), and vegetable-derived glycerol were utilized for the extraction and synthesis processes. All chemical reagents utilized were of analytical grade.

The raw cotton waste was first mechanically shredded to increase its surface area and thoroughly washed with distilled water to remove terrestrial impurities, dust, and water-soluble extractives. The prepared biomass then underwent a rigorous alkaline treatment to dissolve and remove lignin and hemicellulose, isolating the highly crystalline cellulose. Specifically, 100g of the shredded cotton was immersed in a 5% NaOH solution and heated to 80°C for 2 hours under continuous magnetic stirring. The resulting dark pulp was washed repeatedly with distilled water until a neutral pH was achieved, indicating the complete removal of the alkali. To yield purified, distinctly white cellulose fibers, bleaching was subsequently performed using a 4% H_2O_2 solution at 60°C for 90 minutes.

To formulate the bioplastic, the purified cellulose was dissolved in a dilute acetic acid solvent system to form a highly viscous, homogeneous suspension. Glycerol was introduced to the suspension in varying weight percentages relative to the dry cellulose mass (10%, 20%, and 30% w/w) to evaluate the dose-dependent effects of the plasticizer. The mixtures were heated to 70°C and stirred vigorously at 500 rpm for 45 minutes to ensure uniform plasticizer distribution. The resulting hydrogels were cast evenly into flat glass Petri dishes and placed in a convection oven at 50°C for 24 hours to evaporate the solvent and form the final solid bioplastic films.

Characterization of the synthesized films focused on mechanical viability and environmental impact. Tensile strength and elongation at break were measured utilizing a universal testing machine at a consistent crosshead speed of 5 mm/min. For biodegradability, film samples measuring 2 cm x 2 cm were precisely weighed, buried 5 cm deep in locally sourced agricultural soil, and maintained at a controlled ambient room temperature. The samples were exhumed, carefully cleaned of loose soil debris, and re-weighed every 10 days for a total span of 30 days to calculate the progressive weight loss percentage.

Results and discussion

The addition of the glycerol plasticizer significantly influenced the macroscopic physical properties and the internal polymer matrix of the cellulose films. Pure cellulose films formulated without any plasticizer were highly rigid, brittle, and fractured easily upon minimal handling, confirming the restrictive nature of their dense hydrogen-bonded networks. As detailed in the experimental data, increasing the glycerol content progressively improved the flexibility and elasticity (elongation at break) of the films but inversely diminished their ultimate tensile strength. The 10% glycerol formulation yielded a highly rigid film with a tensile strength of 22.4 MPa but a low elongation of only 12.5%. Conversely, the 30% glycerol formulation produced a highly flexible, almost tacky film with an elongation of 58.2% but a diminished tensile strength of 9.8 MPa.

Table 1: Mechanical properties of cotton-cellulose bioplastic films with varying glycerol concentrations.

Sample Formulation	Tensile Strength (MPa)	Elongation at Break (%)	Visual Characteristics
10% Glycerol	22.4	12.5	Rigid, slightly brittle
20% Glycerol	15.2	34.0	Flexible, transparent
30% Glycerol	9.8	58.2	Highly flexible, tacky

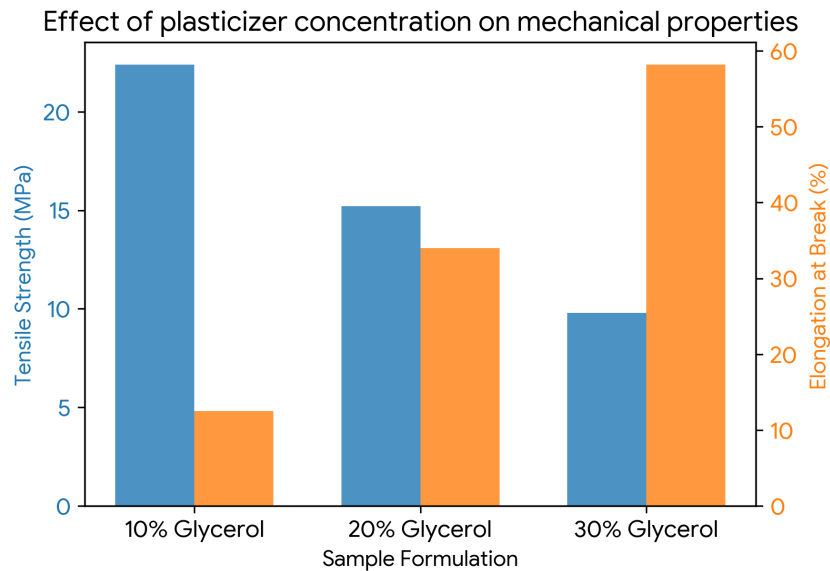


Figure 1: Effect of plasticizer concentration on mechanical properties.

The 20% glycerol formulation emerged as the optimal formulation, successfully bridging the mechanical extremes. It yielded a tensile strength of 15.2 MPa and an elongation at break of 34.0%. This specific formulation effectively mimics the tactile properties and structural integrity of conventional low-density polyethylene (LDPE) packaging films, making it the most viable candidate for commercial applications.

Furthermore, a critical metric for any sustainable material is its end-of-life environmental impact. The synthesized bioplastic films demonstrated excellent and rapid degradation profiles in natural soil conditions. This degradation is driven by the synergistic action of soil microbiota (bacteria and fungi) actively cleaving the cellulose polymer chains, aided by the easily digestible nature of the glycerol molecules.

Table 2: Weight loss percentage of bioplastic films in agricultural soil over 30 days.

Time (Days)	10% Glycerol Weight Loss (%)	20% Glycerol Weight Loss (%)
Day 10	12%	18%
Day 20	31%	45%
Day 30	54%	68%

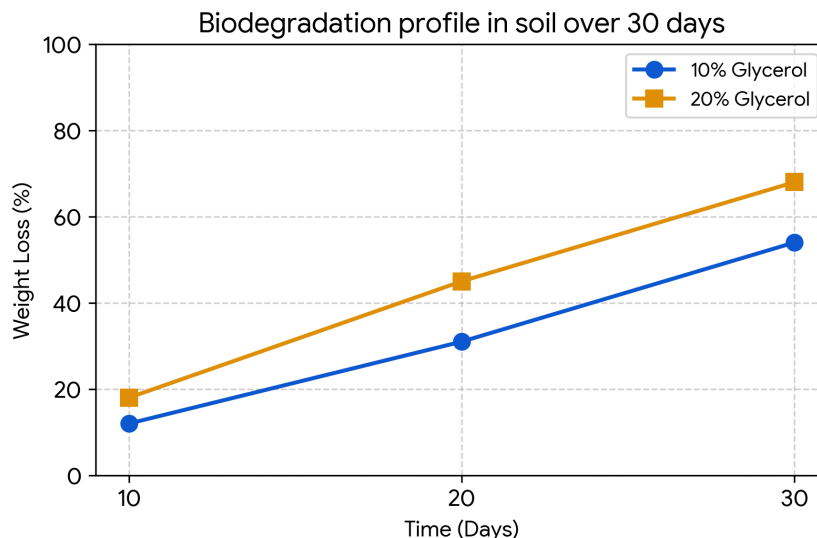


Figure 2: Biodegradation profile of synthesized bioplastic films in soil over 30 days.

The empirical data indicates that a higher glycerol content actively accelerates the degradation process. The 20% glycerol film exhibited a remarkable 68% mass loss within just 30 days of soil burial, compared to a 54% mass loss for the 10% glycerol film. This accelerated breakdown is likely due to the plasticizer successfully increasing the free volume between the polymer chains, which in turn allows ambient soil moisture and microbial enzymes to penetrate the structural matrix of the plastic much more efficiently.

Conclusions

Sustainable, functional bioplastic films were successfully synthesized from locally sourced cotton agricultural waste. Through rigorous alkaline extraction to isolate cellulose and the subsequent incorporation of a glycerol plasticizer, the resulting materials exhibited highly promising mechanical properties alongside excellent environmental biodegradability. The formulation containing 20% glycerol yielded the best overall performance matrix. This research explicitly demonstrates the vast, untapped potential of utilizing local agricultural byproducts to engineer eco-friendly alternatives to conventional synthetic plastics. By doing so, this study contributes an actionable framework for establishing a greener, circular economy that simultaneously addresses agricultural waste management and global plastic pollution.

CRedit authorship contribution statement

Otabek Nasimov: Conceptualization, Methodology, Writing – original draft.

Kumush Toymasova: Investigation, Data curation, Formal analysis.

Muslima Orolova: Validation, Writing – review & editing.

Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Ethics approval and consent to participate

Not applicable. No human or animal subjects were involved in this study.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declaration of generative AI and AI-assisted technologies in the writing process

Statement: During the preparation of this work the author(s) used generative AI in order to structure the draft and match NSRI formatting guidelines. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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