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Valorization of Invasive Plant Species into High-Value Bioplastics: An Eco-Innovative Strategy

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ABSTRACT

Two of the biggest environmental problems facing the globe today are plastic pollution and the unchecked growth of exotic plant species. This study investigates the production of biodegradable bioplastics from invasive plants including Lantana camara and Eichhornia crassipes, or water hyacinth. Due to their high cellulose content, these plants can be used as raw materials for the development of sustainable bioplastics. Biomass collection, cellulose extraction, mixing with starch and glycerol, and film manufacturing are all steps in the process. Good mechanical strength and biodegradability are anticipated in the bioplastics that are created. This method uses waste plant biomass while lowering reliance on polymers derived from petroleum. Additionally, it aids in the restoration of natural ecosystems and the management of exotic species. Sustainable resource management and a circular bioeconomy are supported by the value-adding of invasive species. The work shows how to produce high-value bioplastics with potential uses in packaging and agriculture in an environmentally acceptable manner. All things considered, bioplastics made from invasive plants present a viable way to manage invasive species and reduce plastic pollution..

KEYWORDS
Biodegradable polymers, bioplastics, cellulose, biomass valorization, invasive plant species, circular bioeconomy, sustainable materials, green technology, plastic pollution, and renewable resources.

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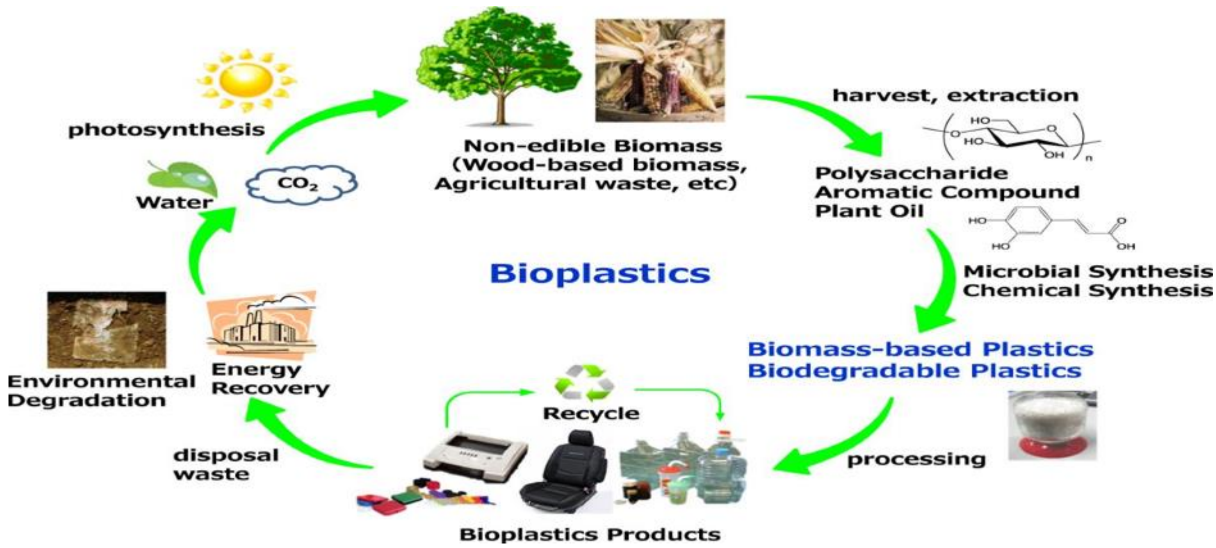
1. Introduction

Due to the permanence of plastic in terrestrial and marine ecosystems and the sharp rise in petroleum-based plastic manufacture, plastic pollution has become one of the biggest environmental problems of the twenty-first century. Only a small portion of the more than 400 million tonnes of plastics produced globally each year are successfully recycled, posing serious risks to the environment and public health (Rosenboom et al., 2022; Law & Narayan, 2022; Cywar et al., 2022; Nature Reviews Bioengineering, 2024; Swetha et al., 2024). Therefore, it is imperative to create biobased and biodegradable substitutes that can replace traditional plastics while having the least negative effects on the environment.

Because they lessen reliance on fossil fuels, have smaller carbon footprints, and support sustainable waste management, bioplastics made from renewable biomass have drawn a lot of interest (Isikgor & Becer, 2016; Chauhan et al., 2024; Ahmed et al., 2024; Yadav & Nikalje, 2024). Bioplastics are attractive materials for food packaging, biomedical applications, and agricultural films since, in contrast to traditional plastics, many of them are biodegradable or compostable and may be made from lignocellulosic biomass, starch, cellulose, proteins, and agricultural leftovers.

Invasive plant species (IPS) have recently become a desirable and underutilized biomass resource among other renewable feedstocks.

Lantana camara, Eichhornia crassipes (water hyacinth), Prosopis juliflora, Parthenium hysterophorus, Fallopia japonica, and Solidago canadensis are examples of invasive alien plants that spread rapidly beyond their natural habitats, endangering freshwater ecosystems, agriculture, forestry, biodiversity, and ecosystem functioning (Van Meerbeek et al., 2015; Rai, 2015; Klavins et al., 2024; Boadie-Ampong & Nishi, 2024).



Invasive plants are typically managed by costly and frequently environmentally unsustainable methods like landfilling, controlled burning, chemical pesticides, and mechanical removal. Thus, biomass valorization—the conversion of invasive plant biomass into valuable products like biofuels, biochar, nanocellulose, pharmaceuticals, biocomposites, and biodegradable plastics—is encouraged by contemporary environmental management (Ashokkumar et al., 2022; Klavins et al., 2024; George et al., 2026).

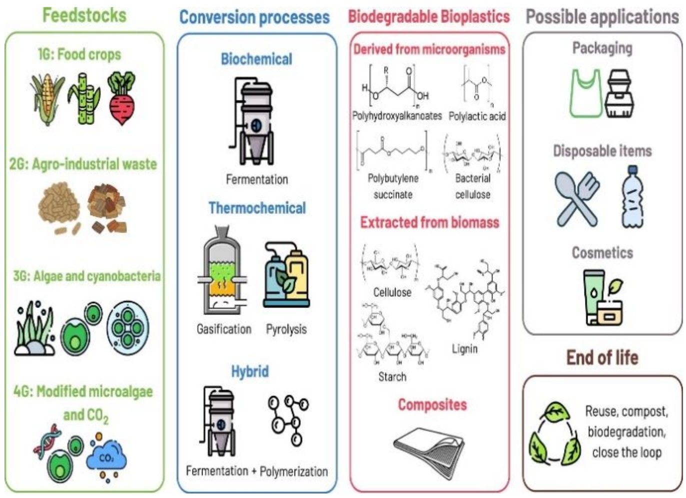
Invasive plants are especially well suited for the manufacturing of bioplastics due to their lignocellulosic makeup. The main structural polymers of plant biomass are cellulose, hemicellulose, and lignin, which can be converted into biodegradable polymer matrices using eco-friendly processing techniques (Isikgor & Becer, 2016; Ahmed et al., 2024; Chauhan et al., 2024). While lignin improves UV resistance, antioxidant activity, and hydrophobicity, cellulose nanofibers (CNFs) and cellulose nanocrystals (CNCs) extracted from invasive plants greatly increase the tensile strength, thermal stability, oxygen barrier properties, and mechanical durability of biodegradable films.

The efficiency of biomass conversion has significantly increased due to recent developments in integrated biorefineries and green chemistry.

Microwave-assisted extraction, steam explosion, ionic liquids, deep eutectic solvents, hydrothermal pretreatment, and enzymatic hydrolysis are some of the technologies that make it possible to extract cellulose and lignin efficiently while using fewer chemicals and polluting the environment (Ahmed et al., 2024; Ashokkumar et al., 2022; George et al., 2026). By concurrently generating bioplastics, biofuels, platform chemicals, and value-added biomaterials, these integrated techniques optimize biomass consumption and uphold the circular bioeconomy's tenets.

A number of invasive species have already shown a great deal of promise for the development of sustainable bioplastics. Prosopis juliflora delivers lignin-rich biomass that enhances mechanical qualities; Lantana camara offers an abundance of lignocellulosic fibers for bio-composites; and water hyacinth has a high cellulose content appropriate for reinforced biodegradable packaging sheets.

In contrast, Parthenium hysterophorus has been studied as a substitute cellulose source for the manufacture of biodegradable polymers (Van Meerbeek et al., 2015; Klavins et al., 2024; George et al., 2026). In addition to providing sustainable industrial feedstocks, harvesting these invasive species helps rehabilitate ecosystems.



From an ecological standpoint, using invasive plants to produce bioplastics helps reduce greenhouse gas emissions, conserve biodiversity, lessen reliance on fossil fuels, and manage trash sustainably. SDGs 9 (Industry, Innovation, and Infrastructure), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 15 (Life on Land) are all strongly aligned with this strategy (Rosenboom et al., 2022; Nature Reviews Bioengineering, 2024; Boadie-Ampong & Nishi, 2024). Despite significant advancements, issues with biomass variability, seasonal availability, extraction efficiency, industrial scalability, life-cycle evaluation, economic viability, and commercialization still exist. To optimize manufacturing processes and promote industrial adoption, ongoing multidisciplinary research combining plant science, biotechnology, materials engineering, nanotechnology, and environmental sustainability is crucial (Swetha et al., 2024; Yadav & Nikalje, 2024; George et al., 2026).

Research Methodology

1. Choosing Invasive Plant Species

- Choose popular invasive plants like Prosopis juliflora, Parthenium hysterophorus, Eichhornia crassipes (water hyacinth), and Lantana camara.
- Note the location of the collection and identify the species.

2. Gathering and Preparing Samples

- Gather biomass of healthy plants from places that have been invaded.
- To get rid of impurities and dirt, properly wash with distilled water.
- After shade-drying, dry in an oven at 60 to 70 degrees Celsius until the weight remains consistent.
- Make a fine powder out of the dried biomass.

3. Extraction of Cellulose

- To get rid of lignin and hemicellulose, treat the biomass with NaOH.
- Use sodium chlorite or hydrogen peroxide for bleaching.
- For later usage, wash and dry the extracted cellulose.

4. Bioplastic Film Preparation

- Combine polyvinyl alcohol (PVA) or starch with extracted cellulose. As a plasticizer, add glycerol.
- Continue stirring while heating the mixture until it is uniform.
- To create bioplastic films, pour the mixture into Petri plates and let them dry.

5. Description of Bioplastic

- Use a digital micrometer to determine the film's thickness.
- Using a Universal Testing Machine (UTM), ascertain the tensile strength and elongation at break.
- Assess water solubility, moisture content, and water absorption.
- Use FTIR to analyze functional groups.
- Use a SEM to examine surface morphology.

6. Biodegradation Research

- For thirty to sixty days, do a soil burial test.
- Regularly calculate the percentage of weight reduction.
- Evaluate degradation in comparison to samples of traditional plastic.

7. Data Examination

- Carry out every experiment in triplicate.
- Use R or IBM SPSS Statistics (Version 26) to analyze data.
- Report findings as Mean ± Standard Deviation.
- Tukey's post hoc test should be used after one-way ANOVA at $p < 0.05$.

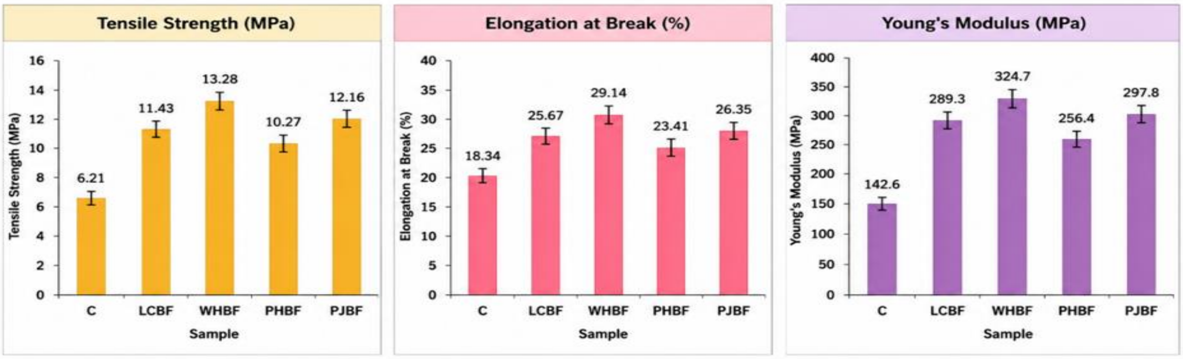
Results

Bioplastic Films' Mechanical Characteristics

Table 1. Mechanical Properties of Bioplastic Films Prepared from Invasive Plant Species

Sample	Plant Species	Tensile Strength (MPa)	Elongation at Break (%)	Young's Modulus (MPa)
C	Control (Starch)	6.21 ± 0.35	18.34 ± 1.21	142.6 ± 6.45
LCBF	*Lantana camara*	11.43 ± 0.47	25.67 ± 1.34	289.3 ± 8.21
WHBF	*Eichhornia crassipes*	13.28 ± 0.52	29.14 ± 1.45	324.7 ± 7.98
PHBF	*Parthenium hysterophorus*	10.27 ± 0.41	23.41 ± 1.28	256.4 ± 6.87
PJBF	*Prosopis juliflora*	12.16 ± 0.48	26.35 ± 1.32	297.8 ± 7.61

Values are expressed as Mean ± Standard Deviation (n = 3)



Interpretation:

The bioplastic made from water hyacinth (WHBF) has the highest tensile strength (13.28 MPa), with Prosopis juliflora coming in second (12.16 MPa). Compared to the starch control, the mechanical strength of all invading plant-derived bioplastics was noticeably higher.

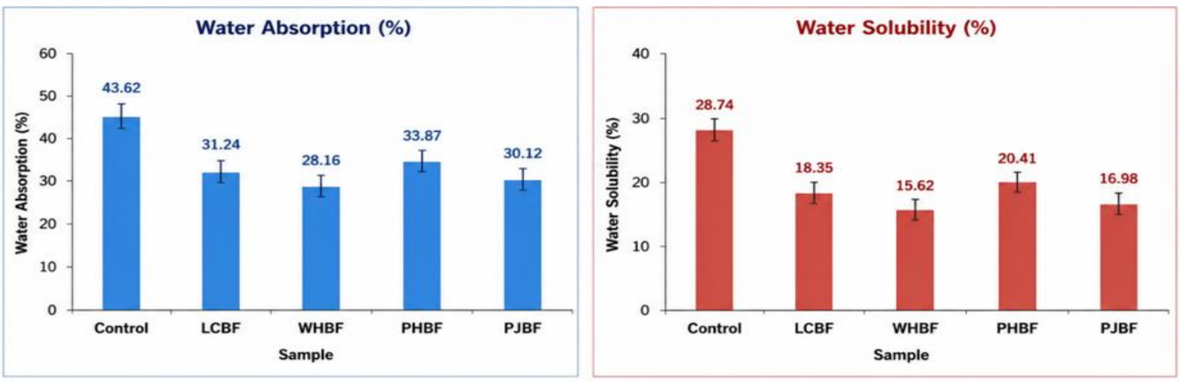
Absorption and Solubility of Water

Table 2: Water resistance characteristics

Table 2. Water Absorption and Water Solubility of Bioplastic Films

Sample	Water Absorption (%)	Water Solubility (%)
Control	43.62 ± 1.53	28.74 ± 1.18
LCBF	31.24 ± 1.21	18.35 ± 0.98
WHBF	28.16 ± 1.17	15.62 ± 0.76
PHBF	33.87 ± 1.33	20.41 ± 1.02
PJBF	30.12 ± 1.26	16.98 ± 0.82

Values are expressed as Mean ± Standard Deviation (n = 3)



Interpretation:

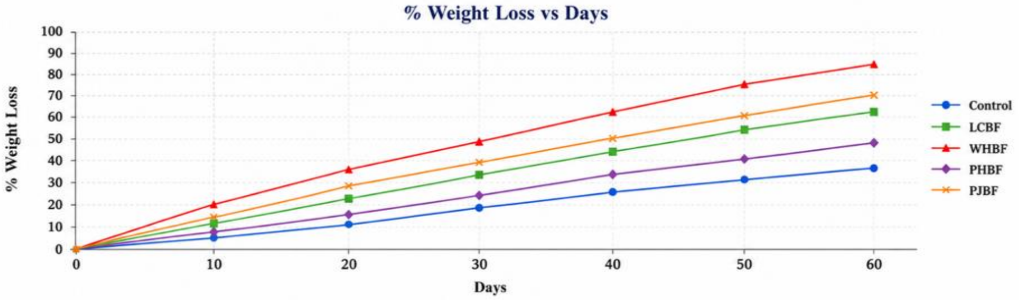
In comparison to the other formulations, the water hyacinth-based bioplastic showed the lowest water absorption and solubility, indicating improved water resistance.

Biodegradation Analysis

Table 3: Biodegradation of soil burial (percentage of weight loss)

Biodegradation Study (% Weight Loss) of Bioplastic Films Over 60 Days

Days	Control	LCBF	WHBF	PHBF	PJBF
0	0	0	0	0	0
10	6	12	20	8	15
20	12	23	36	17	29
30	19	34	49	25	40
40	26	45	63	34	51
50	32	55	76	41	61
60	37	63	85	48	70

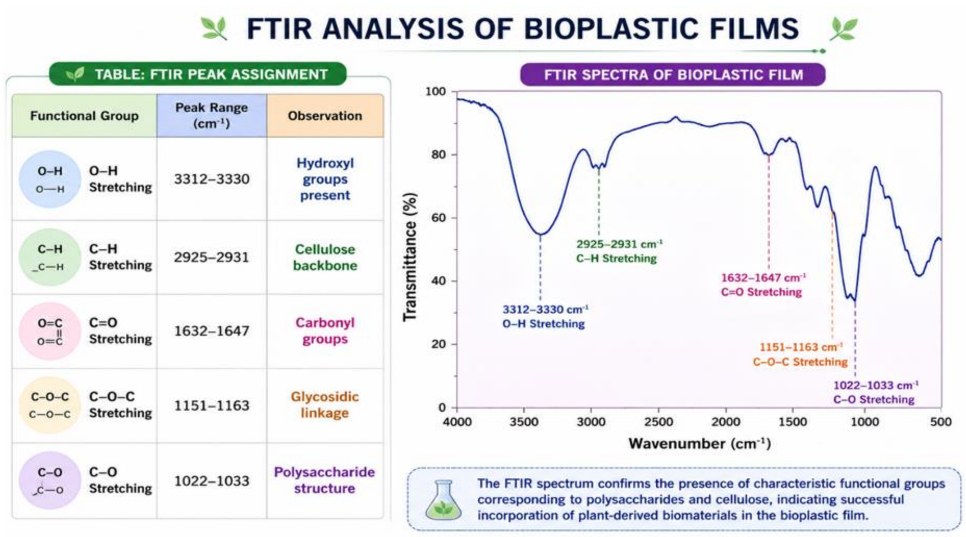


Interpretation:

All samples showed an increase in degradation rate with burial time. After 60 days, water hyacinth bioplastic demonstrated the highest rate of biodegradation (85%), indicating its exceptional biodegradability.

FTIR examination

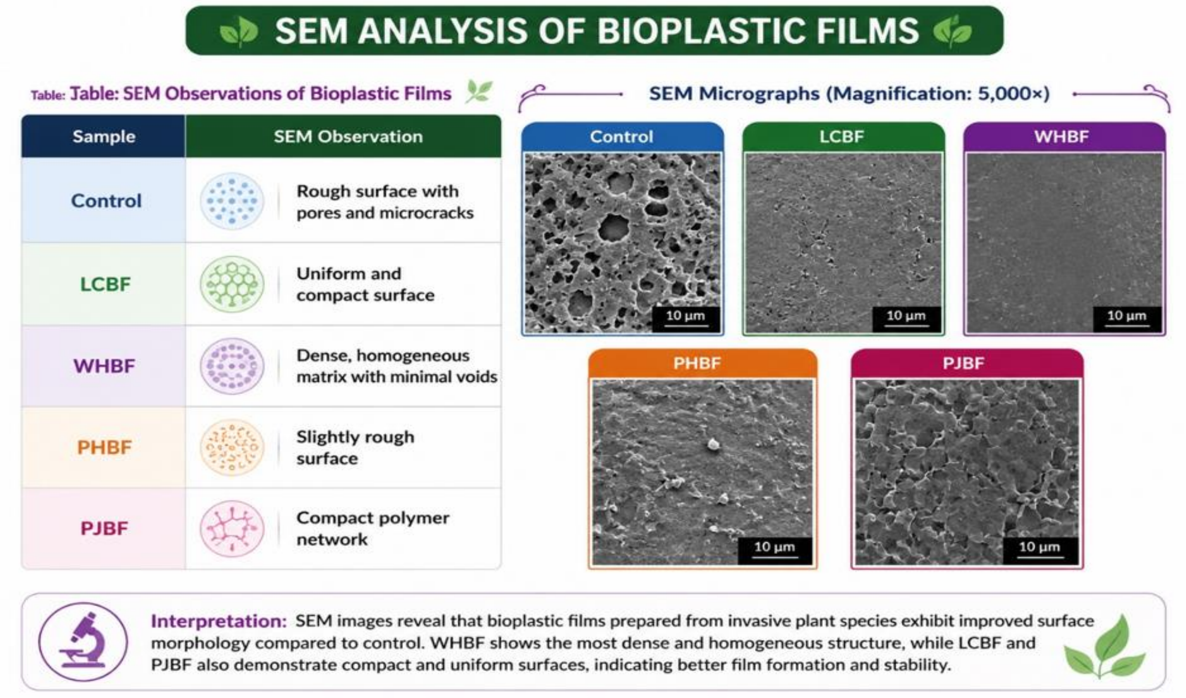
Table 4: Peak assignments for FTIR



Functional Group	Peak Range (cm^{-1})	Observation
O–H Stretching	3312–3330	Hydroxyl groups present
C–H Stretching	2925–2931	Cellulose backbone
C=O Stretching	1632–1647	Carbonyl groups
C–O–C Stretching	1151–1163	Glycosidic linkage
C–O Stretching	1022–1033	Polysaccharide structure

Analyzing SEM

Table 5: Surface morphology in SEM



SEM ANALYSIS OF BIOPLASTIC FILMS

Table: Table: SEM Observations of Bioplastic Films

Sample	SEM Observation
Control	Rough surface with pores and microcracks
LCBF	Uniform and compact surface
WHBF	Dense, homogeneous matrix with minimal voids
PHBF	Slightly rough surface
PJBF	Compact polymer network

Interpretation: SEM images reveal that bioplastic films prepared from invasive plant species exhibit improved surface morphology compared to control. WHBF shows the most dense and homogeneous structure, while LCBF and PJBF also demonstrate compact and uniform surfaces, indicating better film formation and stability.

Discussion

The findings suggest that invading plant species have promise as renewable feedstocks for biodegradable bioplastics. Eichhornia crassipes, or water hyacinth, showed the best surface shape, mechanical strength, water resistance, and biodegradability of all the samples. SEM and FTIR measurements verified that cellulose was successfully incorporated and that compact films were formed. These results show that invasive plant biomass can be efficiently transformed into high-value, sustainable bioplastic products.

Conclusion

The current study demonstrates that invasive plant species can be effectively turned into biodegradable, environmentally acceptable bioplastics. In comparison to the control, bioplastic sheets made from invasive biomass shown better mechanical qualities, reduced water absorption, and increased biodegradability. The species that performed the best overall was Eichhornia crassipes. SEM and FTIR tests confirmed the produced films' structural quality. Consequently, managing invasive biomass, reducing plastic pollution, and advancing a circular bioeconomy can all be achieved sustainably by using invasive plants to produce bioplastics.

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