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Original research paper

Preparation, Structural Characterization, and Biodegradability of Cassava- and Potato-Starch-Based Bioplastics

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Abstract: The growing demand for sustainable plastics stems from the environmental hazards posed by conventional petroleum-based products. This study investigates the synthesis and characterization of bioplastics derived from cassava and potato starch and compares their properties with polyethylene. Bioplastics were fabricated using glycerol and acetic acid as plasticizers. Optical microscopy revealed that effective starch gelatinization and uniform plasticizer distribution help prevent microcracking in the material. FTIR (Fourier-transform infrared) spectroscopy confirmed the presence of hydroxyl, carbonyl, and glycosidic bond peaks, indicating successful bioplastic formation. Solubility tests showed that starch-based bioplastics dissolved in both 10% sodium hydroxide and water at 90–100 °C, whereas polyethylene remained insoluble under the same conditions. Moisture interaction tests indicated that cassava bioplastics absorbed water and swelled, while potato-based samples exhibited a weight reduction. Degradability tests demonstrated that cassava and potato bioplastics decomposed within 20 and 15 days, respectively, while polyethylene did not degrade. These findings highlight the potential of starch-based bioplastics as environmentally friendly alternatives to conventional plastics. However, their mechanical properties vary depending on the starch source. Future efforts should focus on optimizing gelatinization and plasticizer incorporation to improve structural integrity and performance.

Keywords: Bioplastic, starch, cassava, potato, polyethylene, biodegradation

शोधसार: परम्परागत प्लास्टिकहरुले वातावरणमा पार्ने नकारात्मक प्रभावका कारण दिगो र वातावरणमैत्री प्लास्टिकको माग दिनप्रतिदिन बढ्दै गएको सन्दर्भमा प्रस्तुत अध्ययनमा स्थानिय बजारमा उपलब्ध एक प्रकारको तरुल र आलुबाट निकलिएको स्टार्चबाट ग्लिसरोल र एसिटिक एसिडलाई प्लास्टिसाइजरका रूपमा प्रयोग गरेर बायोप्लास्टिक बनाई तीनिहरुको गुणहरूलाई पोलीइथिलीनसँग तुलना गरिएको छ। बायोप्लास्टिक बनाउन ग्लिसरिन र एसिटिक एसिड प्रयोग गरिएको छ जसले यसलाई लचिलो बनाउँछ। माइक्रोस्कोपले हेर्दा, स्टार्च राम्रोसँग पकाएर प्लास्टिसाइजर समान रुपले मिलाएमा बायोप्लास्टिक नचर्किने देखियो। फुरियर-ट्रान्सफर्म इन्फ्रारेड परीक्षणले यसमा हाइड्रोक्सिल, कार्बोनिल, र ग्लाइकोसिडिक बोन्डहरू भेटिएकोले बायोप्लास्टिक सफलतापूर्वक बनेको पुष्टि भयो।बायोप्लास्टिकका नमुनाहरुलाई पानी र सोडियम हाइड्रोक्साइडमा परीक्षण गर्दा, ९०–१०० °C मा पग्लिएर घुलेको तर पोलिथिलिन नपग्लिएको पाइयो। पानी अवशोषण परिक्षण अनुसार, नमीले तरुलको बायोप्लास्टिक फुल्लियो भने आलुको बायोप्लास्टिकको तौल घटेको पाइयो। माटोमा कुहिने परिक्षण गर्दा तरुलको बायोप्लास्टिक २० दिनमा र आलुको बायोप्लास्टिक १५ दिनमा कुहिएको तर पोलिथिलिनमा २० दिन सम्म कुनै प्रभाव नपरेको पाइयो। यसले स्टार्चबाट बनेको बायोप्लास्टिक, पेट्रोलियम प्लास्टिकको विकल्प हुन सक्ने देखाउछ। तर तरुल र आलुको बायोप्लास्टिकको गुण फरक फरक छन्। भविष्यमा स्टार्चलाई राम्रोसँग पकाउने र प्लास्टिसाइजर मिलाउने तरिका अझ बढी अध्ययन गर्नुपर्ने देखिन्छ जसवाट ती बायोप्लास्टिकहरुको गुणस्तर र टिकाउपन बढाउन सकिनेछ।

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INTRODUCTION

Bioplastics are materials derived from renewable biological sources such as starch, cellulose, or other polysaccharides, and have emerged as an environmentally favorable alternative to conventional synthetic plastics [1]. Starch is particularly attractive among various biopolymers due to its abundance, low cost, and film-forming capability [2,3]. Starch is a naturally occurring polysaccharide macromolecule that displays polymer-like properties, making it a promising material for producing bioplastics. These bioplastics significantly reduce plastic waste's environmental footprint [4,5]. Many bioplastics allow natural decomposition through micro-organism action because they differ from conventional plastics [6]. In contrast, conventional synthetic polymers like polyethylene (PE), polypropylene (PP), and polystyrene (PS) are produced from petrochemical sources and are characterized as being non-biodegradable and resistant to degradation [7]. However, Plastic has become essential for every aspect of human life, including packaging electronic goods and household items, and transport vehicles. Such polymers derived from non-renewable petroleum resources accumulate in landfills and natural habitats, contributing to pollution and ecological harm that can persist for extended periods of 200 years [8,9]. This increasing concern has accelerated the pursuit of sustainable alternatives, with bioplastics as a strong, promising solution.

Bioplastics exhibit applications across medicine, cosmetics, the automotive industry, food packaging, and agriculture because of their degradability, along with their manufacturing dependence on waste materials [10]. The medical domain discovers beneficial applications for natural waste-based bioplastics because they exhibit reduced potential to cause allergic reactions as compared to petroleum-based materials. Since starch is inexpensive, versatile, and optically clear, it has emerged as the most popular and crucial ingredient in edible and biodegradable films among the different kinds of polysaccharides, including cellulose, gums, starch, and chitosan [11]. The development of advanced technology now enables creative uses of cellulose and starch together with other bio-based materials for food packaging [12,13]. Plastic manufacturers within the sector mostly deploy starch-based polymers together with polylactic acid (PLA) and cellophane materials for their distinct functional properties. The use of biodegradable mulch films in agriculture proves cost-efficient because they reduce both operational expenses and waste disposal expenses as they are designed to be utilized once and then safely combined with soil [14].

However, starch-based bioplastics often face challenges related to mechanical strength, water sensitivity, and durability compared to conventional plastics like polyethylene [15,16]. Recent research has focused on optimizing the formulation of starch-based bioplastics through the use of plasticizers, blending agents, and processing techniques to enhance their physical and chemical properties [17,18]. Comparative studies between bioplastics derived from cassava and potato starch and conventional polyethylene are essential to evaluate their performance, biodegradability, and potential for real-world applications [15].

Another significant concern in bioplastic production is identifying a reliable and sustainable source of starch. Among the various options, cassava and potato starch emerge as promising raw materials, as they are major agricultural sources of starch that are widely cultivated and readily available in many regions [19]. The extraction and development of bioplastics from these starches offers a viable pathway to produce bioplastics. Furthermore, the combined treatment of starch with plasticizers like glycerol and acetic acid allows the creation of flexible and water-soluble films [20]. These films degrade at a much faster rate compared to conventional polyethylene, making them an environmentally friendly alternative [21].

This research article aims to prepare and characterize bioplastics from cassava and potato starch and systematically compare their properties with those of conventional polyethylene. By assessing mechanical, thermal, and biodegradability characteristics, this study seeks to contribute to the development of bioplastics.

MATERIALS AND METHODS

Materials

Cassava and potatoes were obtained from the local market in Kathmandu. Glycerol, acetic acid, 10% NaOH, 10% HNO_3, acetone, benzene, and distilled water were purchased from Kathmandu, manufactured by Himedia Laboratories Pvt. Ltd., India, and used without further purification.

Methods

Preparation of bioplastic: 2 kg of each cassava and potato was weighed, washed, peeled, cut, and soaked in distilled water for 48 hrs. Then they were ground using a clean kitchen blender and decanted for 4 hrs and filtered using a muslin cloth to remove excess water. The filtered mass was then sun-dried for 24 hrs. The dry starch was then mixed with water, glycerol, and acetic acid, which was warmed in a water bath and left to set for a week in a mold [22].

Surface Morphology: Surface morphology characterization was done by using a Boeco BM-800 laboratory binocular microscope and digitally recorded with a Boeco B-CAM 16. The samples were prepared on a glass slide, using immersion oil, and covered with a coverslip.

FTIR analysis: The FTIR spectra were obtained using an IR Affinity-1S FTIR Spectrophotometer (Shimadzu) to analyze species, functional groups, and vibrational modes linked to each peak. The spectra were observed within the 400-4000 cm^{-1} spectral range with a resolution set at 4 cm^{-1}.

Water absorption test: The samples of equal weight (w_1) having similar shapes were prepared and then dipped into the water for 12 hrs. These samples were dried with the help of filter paper to minimize error by removing surface water and weighed (w_2) [22].

Solubility test: The solubility tests were performed in various solvents ranging from polar to non-polar (water, 10% NaOH, 10% HNO_3, ethanol, acetone, and benzene). The prepared samples were cut into small pieces of weight 0.1g and put into 10 mL test tubes containing 5 mL of solvents. The solubility was observed at both room temperature and elevated temperature of 90 °C [22].

Biodegradability test: A biodegradability test was done by using the soil burial method. Samples were cut and weighed to equal 0.1g in similar shapes. These samples were then buried in a box containing moist soil at a depth of 10 cm for 20 days at room temperature and checked for weight loss at every 5-day intervals by cleaning, drying, and weighing the samples [23].

RESULTS AND DISCUSSION

Surface morphology

The study of bioplastic surface features was conducted through optical microscopy. **Figures 1a and 1b** show the distribution of starch and plasticizers, indicating successful blending [24]. These optical micrographs displayed surface fractures accompanied by cracks, which are likely attributed to the presence of α-1,4-glucosidic bonds in the starch matrix, probably due to its naturally amorphous characteristics [25,26].

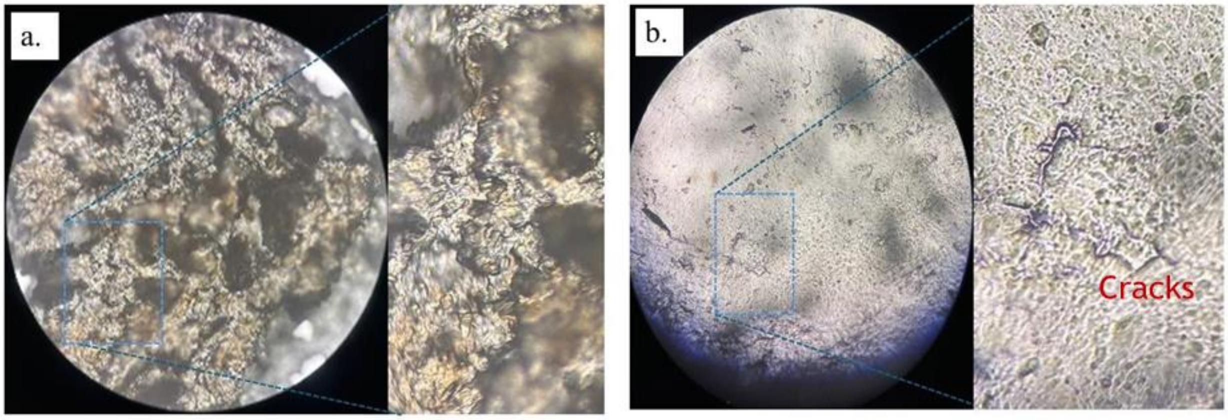

Figure 1. Optical micrographs of **a.** Cassava starch bioplastic and **b.** Potato starch bioplastic.

FTIR analysis

The FTIR spectra of the bioplastics (**Figure 2**) exhibited characteristic peaks confirming the presence of starch, glycerol, and acetic acid. A broad absorption band between 3600–3000 cm⁻¹ was observed, corresponding to O–H stretching vibrations, indicating the hydroxyl groups from starch and glycerol [27,28]. The peak at 2929 cm⁻¹ was attributed to C–H stretching, representing the alkyl groups present in the biopolymer matrix [27]. A distinct peak at 1643 cm⁻¹ was assigned to C=O stretching vibrations, confirming the incorporation of acetic acid within the bioplastic structure [29]. Furthermore, the peak at 1079 cm⁻¹ indicated the C–O–C stretching of glycosidic bonds in the starch backbone, while the peak at 1015 cm⁻¹ was associated with C–O–H bending vibrations, supporting the presence of polysaccharide and polyol groups [30]. These results collectively confirm the incorporation of glycerol and acetic acid as plasticizers in the successful formation of starch-based bioplastics.

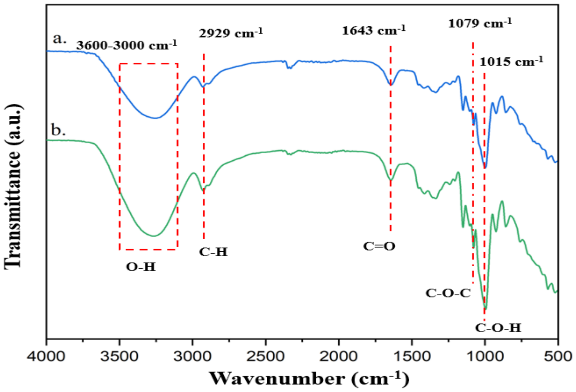

Figure 2. FTIR spectrum of bioplastic **a.** Cassava starch **b.** Potato starch.

Water absorption test

A water absorption analysis involved three plastic types, which included cassava-based bioplastic, potato-based bioplastic, and commercial polyethylene. The weight of each sample before and after being soaked in water was noted as shown in **Table 1**, which is also represented graphically in **Figure 3**.

Table 1. Values of water absorption test on different plastic types.

Sample	**Initial Weight (g)**	**Final Weight (g)**	**Water Absorption (%)**
Cassava bioplastic	0.1	0.17	70
Potato bioplastic	0.1	0.09	-10
Commercial polyethylene	0.1	0.1	0

Among the three samples, cassava showed the highest amount of water absorption, indicating a 70% increase after being soaked in water for 12 hrs. The water molecules entered bioplastics through their porous network and established an interaction with the internal polymer structure [22]. This result was supported by the optical micrograph **(Figure 1),** which indicated the presence of a rupture surface on the plastic materials [26]. The commercial polyethylene sample maintained its constant weight of 0.1 g, indicating 0% water absorption due to its hydrophobic and non-polar structure, as well as its great resistance to water intake [31]. However, the weight of potato-based bioplastic decreased from 0.1 g to 0.09 g after water soaking (**Figure 3**). This is because the materials started dissolving when the aqueous concentration exceeded a specific threshold value [32]. Different water interaction patterns emerge between bioplastic materials and establish synthetic plastic types, according to test observations [33].

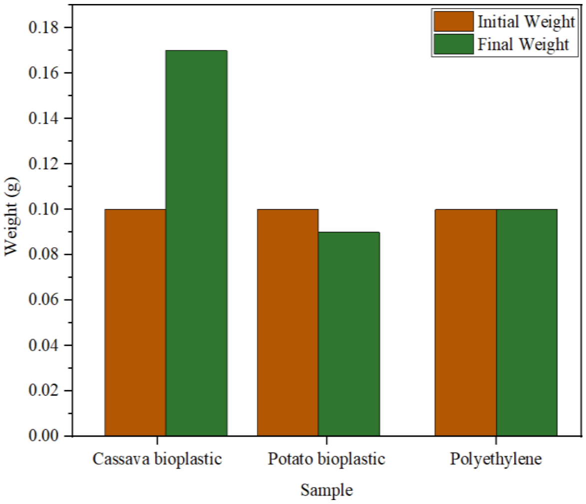

Figure 3. Plot showing weight difference before and after water absorption.

Solubility test

Two types of bioplastics based on cassava starch and potato starch underwent solubility tests involving several solvents under 90 °C and room temperature conditions, which were then compared against traditional polyethylene as indicated in **Table 2**.

Both cassava and potato starch bioplastics showed soluble properties in 10% NaOH at room temperature, yet displayed insolubility against water, 10% HNO_3, ethanol, acetone, and benzene solutions. Exposure to 90 °C allowed the starch-based bioplastics to become partially dissolvable in water and 10% HNO_3, as the elevated temperatures increased their chain network mobility and acidity sensitized them [34]. The dissolving behavior of starch bioplastics in polar solvents and reactive solutions like alkalis and hot water is attributed to the hydrophilic nature of the starch bioplastic that uses hydrogen bonds or hydrolysis to interact with these solvents. The starch-based material's solvent sensitivity matches earlier findings [21,35,36].

Table 2. Solubility test of plastic samples in different solvents.

	Sample	**Water**	**10% NaOH**	**10% HNO_3**	**Ethanol**	**Acetone**	**Benzene**
At room temperature for 24 hrs	Cassava bioplastic	×	✓	×	×	×	×
	Potato bioplastic	×	✓	×	×	×	×
	Commercial polyethylene	×	×	×	×	×	×
At 90 °C	Cassava bioplastic	P. ✓	✓	P. ✓	×	×	×
	Potato bioplastic	P. ✓	✓	P. ✓	×	×	×
	Commercial polyethylene	×	×	×	×	×	×

Note: Insoluble (×), Soluble (✓), Partial soluble (P. ✓)

The tested solvents could not dissolve commercial polyethylene because of its hydrophobic nature, as well as its resistant chemical properties against all solvents [37,38]. This test highlights the biodegradable and environment-responsive characteristics of starch-based bioplastics that are suitable for short-term usage requirements.

Biodegradability test

The test for biodegradability employed the soil burial method. The testing period took place inside one type of soil extending to a depth of 10 cm for 20 consecutive days [39]. The potato starch bioplastic experienced a weight loss of 15% during the first 5 days, and the cassava starch bioplastic lost 20% weight during the same time frame (**Figure 4**). The degradation rate of potato starch bioplastic increased after five days of the experiment and exceeded the degradation rate of cassava starch bioplastic, which may be due to the amylopectin nature, large and porous granules of the potato starch bioplastic that aid the water absorption and increased the rate of degradation process [40,41].

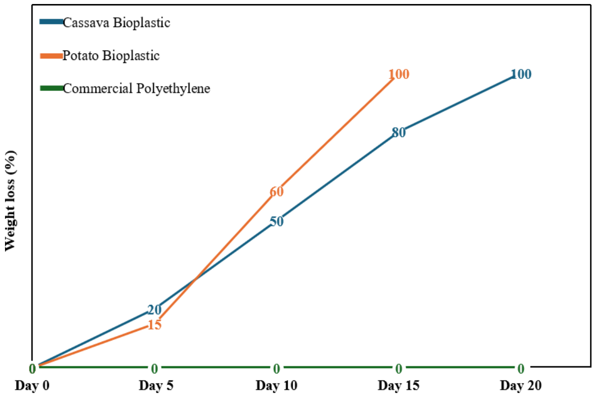

Figure 4. Biodegradability of samples with a percentage loss of the samples at 5-day intervals.

The complete degradation of potato starch bioplastic occurred within 15 days, but cassava starch bioplastic required the full 20-day period to decompose. The film expanded from water absorption from soil and resulted in higher microbial proliferation and enzyme degradation processes that contributed to weight reduction and disruption of the films [23]. On the other hand, the hydroxyl group in starch may have initiated the hydrolysis reaction of the polymer after water absorption, also glycerin, as a hydrophilic plasticizer, reduced the internal hydrogen bond in the polymer chain [42]. Commercial polyethylene did not show any signs of degradation during the 20-day testing period.

CONCLUSION

This research highlights the potential of starch-based bioplastics as a viable biodegradable alternative to conventional plastics. Bioplastic was successfully synthesized using easily available chemicals, making the process accessible and cost-effective. Comprehensive characterization techniques optical microscopy, FTIR spectroscopy, water absorption, solubility, and biodegradability tests, establish the environmental benefits of the starch-based bioplastics. The research showed that commercial polyethylene remained unaffected by all treatment components, confirming its resistance to natural degradation processes. Overall, the results confirm that starch-based bioplastics, particularly those derived from potato starch, exhibit significant environmental compatibility and are well-suited for integration into sustainable manufacturing systems.

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Availability of data and materials

The data will be made available at any time when requested.

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Author Contributions

AT and SD: collecting samples and conducting experiments; NR: analyzing FTIR data and contributing in manuscript writing; SB: analyzing biodegradability data, writing and editing; BBM: analyzing solubility data, contributing in manuscript drafting; OPB: graphics design, analysis of water absorption data, manuscript drafting; MMS: supervision, designing experiments, analysis of data, and writing, reviewing, and editing of the manuscript.

Safety and Ethical Declarations

The safety and ethical considerations for the present work were strictly followed under the direct guidance and supervision of the corresponding authors and mentors.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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