Fabrication and Characterization of Biodegradable Plastic Film from Cassava and Sweet Potato Starch Blend

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Abstract
For decades, Petro-based plastics have found extensive industrial applications and are widely used in everyday life. They are tough, corrosion-resistant, lightweight, and can be moulded into various shapes. However, Petro-based plastics resist natural degradation and produce large amounts of carbon emissions during incineration and disposal. Consequently, they cause environmental contamination and pose a serious threat to environmental health. Starch-based biodegradable plastics offer a promising remedy for these challenges. This study aimed to fabricate a biodegradable plastic from a blend of cassava and sweet potato starch and to determine its physical properties (tensile strength) and biodegradability. The starch was obtained from peeled and finely ground cassava and sweet potatoes. After blending, the starch was gelatinized and plasticized using glycerol. To determine biodegradability, bioplastic strips made from the cassava and sweet potato starch blend were buried in garden and compost soils, and degradation efficiency was evaluated. Tensile strength was determined from the ratio of breaking force to the film's cross-sectional area. The sweet potato starch blend biofilm had a tensile strength of 2.378 MPa, followed by the cassava biofilm at 2.18 MPa; the blend was the lowest at 1.175 MPa. The comparative biodegradability test revealed that the starch blend achieved 100 percent degradability in compost soil and 61.53 percent in garden soil, making it the most biodegradable. These findings indicate that the starch-based bioplastic film synthesized from cassava and sweet potato blends demonstrated the greatest biodegradability and material strength. The blend exhibited the highest biodegradability, particularly in compost soil, indicating strong environmental compatibility. These findings highlight the potential of locally available starch-rich crops as sustainable raw materials for producing eco-friendly alternatives to petroleum-based plastics.

Keywords: Biodegradable, bioplastics, plasticizer, starch blend, tensile strength

Introduction

Global reliance on synthetic plastics derived from fossil fuels has created environmental challenges because they resist natural degradation and generate substantial carbon emissions during disposal (Mohanan et al., 2020). While these synthetic plastics are economically beneficial and have diverse applications, they contribute to significant pollution across all environmental compartments, including terrestrial, marine, and atmospheric environments, posing long-term environmental risks (Epps III et al., 2021). Consequently, scientific research has increasingly focused on developing eco-friendly, sustainable, and biodegradable bioplastics derived from renewable feedstocks, with a major emphasis on starch-based polymeric materials (Anugrahwidya et al., 2021).

Currently, global plastic production is estimated at 367 million tonnes annually, with bioplastics accounting for about 1 percent of the total (Rao et al., 2022). The remainder consists of Petro-based plastics. As of 2021, despite this low production, demand for bioplastics is

growing rapidly because of their diverse applications in agriculture, consumer goods, textiles, and packaging (Shafqat et al., 2021). Within the total bioplastics market, the packaging sector accounts for the largest share at 48 percent (Anugrahwidya et al., 2021).

In recent years, the utilization of starch has expanded beyond its traditional applications as an energy source in the human diet, a sizer in the textile industry, and a binder in paper manufacturing. It is now increasingly applied in the development of degradable bio-based bioplastics as a promising substitute for fossil-based plastics (Özdamar & Ateş, 2018). In addition to its biodegradability, starch is widely used in bioplastic development due to its renewability, abundance, and low oxygen permeability (Zoungranan et al., 2020). However, a major drawback frequently reported in its application as a bioplastic material is its high water sensitivity (Rao et al., 2022).

The literature reports numerous studies on the fabrication of bioplastic materials using various crops as starch sources. Özdamar and Ates (2018) reported that bioplastic derived from tapioca starch, extracted from the cassava plant (*Manihot esculenta*), was smooth, flexible, and strong. Nasir and Othman developed a corn-based bioplastic suitable for use as seedling bags. Their study reported that seedling bags made from corn-based bioplastic offer several advantages, including natural decomposition, nutrient supply to young plants, and the elimination of the need for transplanting during planting due to the bioplastic's natural degradability (Nasir & Othman, 2021). Transparent and low deformation strength albumen/starch based bioplastic have been developed (Gonzalez-Gutierrez et al., 2010). However, the literature provides limited information on developing bioplastics from starch blends. Although some reviews have discussed current developments and trends in the use of starch blends to produce bioplastics with improved mechanical and degradability properties, the available data remain insufficient (Jayarathna et al., 2022).

Starch-based polymers, particularly those developed from abundant crops such as cassava and sweet potato, have distinct advantages. They are naturally biodegradable and carbon-neutral, and their cultivation can also support agricultural economies in developing countries. This study examines the mechanical and degradability benefits of blending these two starches, critically assessing how starch blends may improve both film-forming capabilities and environmental degradation performance when compared to individual starch systems.

Starch is an abundant and biodegradable polysaccharide that has become a promising raw material for the development of bioplastics due to its cost-effectiveness, ability to form thermoplastic films, and its natural availability (do Val Siqueira et al., 2021). Among available starch sources, cassava (*Manihot esculenta*) and sweet potato (*Ipomoea batatas*) have emerged as technologically viable candidates, owing to their high amylose content, cultivation feasibility, and demonstrated thermoplastic behaviour when plasticized (Gadhave et al., 2018). Blending these starches shows particular promise in bridging the mechanical-durability versus biodegradability gap that often limits bioplastic applications.

This investigation explored the fabrication of bioplastic films using a 1:1 (w/w) blend of cassava and sweet potato starch, modified with a glycerol-acetic acid plasticizer system. The mechanical properties of the starch-based biofilm were evaluated through tensile strength testing. Biodegradability was quantified via mass loss measurements in both controlled compost and garden soil under ambient laboratory conditions over 12 weeks. This garden soil setup models the natural soil environment while controlling fluctuating environmental factors.

Tensile strength and biodegradation performance parameters were selected to concurrently assess practical material usability and environmental compatibility—a critical parameter for sustainable material development. This work defined mechanical properties (tensile strength) and biodegradation efficiency as the dependent variables. The starch blend composition ratio was treated as the independent variable. To ensure consistency and validity, several variables were kept constant. These controlled variables included total starch mass per

film, glycerol concentration (maintained at 30% w/w of dry starch), drying temperature, casting volume, and gelatinization conditions.

This work therefore aims to develop a viable alternative to conventional plastics by systematically evaluating a 1:1 w/w blend of cassava and sweet potato starch. The central objective is to determine whether this novel material can achieve a crucial balance: possessing the mechanical performance necessary for practical use while maintaining rapid and complete biodegradability**,** thereby offering a solution to plastic pollution through indigenous bioresources.

Materials and Methods

Bioplastic Film Fabrication Procedure

Fresh cassava roots (*Manihot esculenta*) and sweet potato (*Ipomoea batatas*) were used as starch sources. Root processing involved washing, peeling, and drying within 24 hours of harvest. Analytical grade glycerol (≥99.5% purity, Sigma-Aldrich) and deionized water were used in the plasticizer formulation. A 1:1 (w/w) blend of 10 g each of sun-dried and ground cassava and sweet potato was used for film fabrication. To the starch mixture, a 100 mL of distilled water was added and stirred until the starch completely dissolved.

This blend was modified using a glycerol-acetic acid plasticizer system formulated from a 10 mL of 30 percent glycerol and 6 mL of 5 percent acetic acid, with rapid stirring to prevent starch hydrolysis (do Val Siqueira et al., 2021). The mixture was subsequently heated on a hot plate while continuously stirring and maintaining the temperature between 75 °C and 95 °C (Fluke 62 MAX IR thermometer) until the solution turned translucent (Jayarathna et al., 2022). The gel was evenly spread on a 0.03 mm sheet of aluminium foil and left to cool and dry at ambient laboratory temperature for 48 hours.

The constant weight method was used to confirm the film's dryness, with the film weighed every 6-12 hours until the % mass change was < 1%. After drying, the bioplastic film was carefully peeled from the mould and tested for tensile strength and biodegradability. Control films were also prepared from pure cassava and pure sweet potato starch using the same procedure, maintaining a constant total starch mass of 20 g in each case.

Biodegradability Test

Biodegradation studies were conducted according to the method proposed by Kundu and Payal (2022), in which pre-weighed film samples were buried in soil and percent mass loss was determined after a given incubation period. Biodegradability tests were done using compost soil (pH 7.2 ± 0.3, C/N ratio 25:1) and garden soil (sandy loam, 2.1% organic content) at 28 °C**.** The bioplastic films were weighed and subsequently buried in 2-liter polypropylene containers holding 1.5 kg of growing material. Each medium (garden soil and compost) was replicated three times. The film samples were buried to a depth of 5 cm. The containers were clearly labelled with the sample type and its original mass before burial.

Moisture level was maintained at 60 percent for garden soils and 50 percent for compost by periodically adding 15 mL and 10 mL of distilled water, respectively. The containers were left at room temperature in the laboratory for seven days. Subsequently, the samples were removed, cleaned of any remaining soil particles, and weighed again (Kundu & Payal, 2022). The degradation efficiency, expressed as percentage weight loss, was calculated using the conventional formula in Equation 1, following Nandiyanto et al. (2020). The equation ignores the correction factor for the soil adsorption component (Nandiyanto et al., 2020).

$$Biodegradation\ (\%) = \frac{(W_i - W_f)}{W_i} \times 100 \qquad (1)$$

Where, W_i = Initial mass of biofilm, W_f = Final mass of biofilm after degradation.

The samples were carefully removed from the soil after the incubation period, gently cleaned to remove any remaining soil particles, and then oven-dried at 50 °C to a constant weight before the final mass (W_f) was determined (Kundu & Payal, 2022). This ensured that changes in moisture content did not affect mass loss, except for polymer loss due to biodegradation.

Tensile Strength Test

Tensile strength of biofilm was evaluated following the method proposed by Gabriel et al. (2021). This method calculates tensile strength as the force at break divided by the strip's cross-sectional area, expressed in megapascals (MPa). Bioplastic strips measuring 0.5 cm by 4 cm were cut from defect-free sections of the films for testing. The micrometre screw gauge was used to measure the thickness of the bioplastic strip before stretching. This was done in three replicates to ensure uniform thickness by averaging the measurements. Tensile testing was executed by stretching clamped samples at a steady rate of 10 mm/min until they broke. The force required to cause this break (F_{max}) was measured using a spring scale, zeroed to account for the clip mass (Gabriel et al., 2021).

The obtained measurements were used to compute the cross-sectional area. Force at break (F_{max}) was converted to MPa using Equation 2, a conventional equation for determining tensile strength of starch-based biofilms (Safitri et al., 2022). Tests were considered invalid if breaking occurred within 3 mm of the clamps.

$$Tensile\ strength\ (\sigma) = \frac{F_{max}}{A} \times 10^{-6} \quad (2)$$

Results and Discussion

Biodegradability Test Analysis

Biodegradation testing in this investigation showed that the soil environment (compost versus garden soil) and starch source strongly influence the biodegradability of starch-based bioplastic films, as shown in Table 1. The bioplastic film developed from the starch blend degraded completely in compost, with no recovery from the initial 1.26 g, demonstrating exceptional biodegradability. In garden soil, degradation was moderate, with 1.07 g recovered from 1.61 g; this may be due to high microbial activity in compost, which enhances biodegradability.

Table 1: Degradability of Bioplastic Films from Cassava, Sweet Potato and Starch Blend

Bioplastic Type	Burial Material	Mass Before Burial (g)	Mass After Burial (g)
Starch Blend	Compost	1.26	0.00
Starch Blend	Garden Soil	1.61	1.07
Cassava Starch	Compost	2.25	1.56
Cassava Starch	Garden Soil	2.23	2.44 (wet)
Sweet Potato Starch	Compost	0.60	0.18
Sweet Potato Starch	Garden Soil	0.26	0.10

The bioplastic film developed from the starch blend degraded completely in compost, with no recovery from the initial 1.26 g, demonstrating exceptional biodegradability. In garden soil, the degradation was moderate, with 1.07 g recovered from 1.61 g. This mass loss is attributed to high microbial activity in compost, which enhances degradability. The cassava starch-based bioplastic degraded partially in compost, decreasing from 2.25 g to 1.56 g, but in garden soil, the mass increased slightly from 2.23 g to 2.44 g. This mass gain may reflect

moisture absorption, suggesting that cassava starch-based films are hygroscopic and unstable in humid settings, as observed in related work by Zoungranan et al. (2020).

Although our work associated the variability in degradability with the starch source, related studies have also linked degradability efficiency to the glycerol or plasticizer content, as these enhance flexibility and hygroscopicity, thereby facilitating microbial-assisted degradation (Gurunathan et al., 2025). Existing literature informed the choice of glycerol levels used in this study. Concentrations of glycerol in the range of 20–40% w/w relative to starch mass enhance flexibility while reducing brittleness of starch-derived bioplastic films (Saberi et al., 2016; Zoungranan et al., 2020).

Cassava is rich in amylopectin, which is essential for the flexibility and transparency of the bioplastic film (Chaffa et al., 2024). Sweet potato contains a higher amylose content, a material that enhances the strength and stability of the film (Wahyanti et al., 2023). A 1:1 w/w starch blend was chosen because it provides a balance of these features. Moreover, previous studies have demonstrated that this balanced ratio improves mechanical, functional, and barrier properties (Jayarathna et al., 2022).

The mass in compost decreased from 0.60 g to 0.18 g, and in garden soil from 0.26 g to 0.10 g. Bioplastics degraded more extensively in compost than in garden soil, directly linking the biodegradation process to soil conditions such as microbial density and organic content.

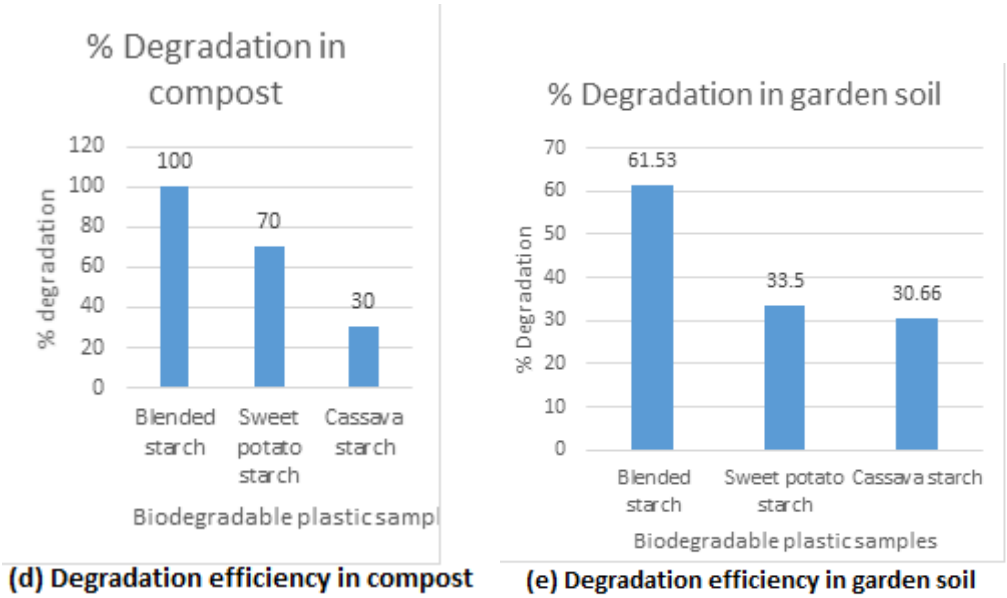
Figure 1 below shows images (a), (b), and (c) of bioplastic films fabricated from starch blends, cassava and sweet potato, respectively. The biofilms are transparent, smooth, and have a continuous surface. These properties are associated with well-gelatinized starch during film formation. During film development, moisture content was maintained at 10–15 percent to allow proper gelatinization of starch (Shah et al., 2017).



Fig. 1: Images of Developed Bioplastic Films from Starch Blend, Cassava and Sweet Potato

Figure 2 shows the biodegradation efficiency findings. Notable observations include 100 percent degradation efficiency of the starch blend in compost, as shown in Figure 2(d), and a decent 61.53 percent efficiency in garden soil, displayed in Figure 2(e). This can be associated with the synergistic effect of the starch blend; possibly, blending modified the polymer network by increasing the porosity of the amorphous structure, thereby enhancing accessibility to microbial enzymes (Thakur et al., 2018). Additionally, blended starch could have higher water

absorption or increased hygroscopicity, increasing water retention and microbial activity (Mohanan et al., 2020).



(d) Degradation efficiency in compost (e) Degradation efficiency in garden soil

Fig. 2: **Degradation Efficiency of Starch Sources in Compost and Garden Soil**

Sweet potato starch degradation efficiency was 70 percent in compost and 33.5 percent in garden soil. Cassava starch showed the lowest % degradability in both compost and garden soils. This is likely due to higher amylopectin content, which creates a branched molecular structure that limits access by microbial enzymes. Consequently, the rate of enzymatic hydrolysis is reduced during composting or soil burial.

Tensile Strength Testing

The tensile strength of the developed bioplastic varied according to the starch source from which it was derived, as shown in Table 2.

Table 2: Tensile Strengths of Starch from Various Sources

Sample type	Average Thickness (10^{-4}m)	Tensile strength (Mpa)
Cassava and sweet potato blend	3.5	1.175
Sweet potato	2.9	2.378
Cassava	2.5	2.18

The sweet potato starch-based bioplastic had the highest average tensile strength (2.378 MPa), despite its lower average thickness (2.9×10^{-4} m). This shows that sweet potato starch may contain a higher amylose-amylopectin content, which forms stronger hydrogen bonds during gelatinization (Lee & Yeo, 2021).

The tensile strength of the fabricated bioplastic film was assessed as the dependent variable. The plasticizer (glycerol) amount and the starch blend composition were the independent variables. Film thickness, gauge length, drying temperature, and the bioplastic film fabrication method served as controlled variables.

The cassava starch-based bioplastic had a tensile strength of 2.18 MPa and a thickness of 2.5×10^{-4} m, indicating good mechanical strength, but relatively lower than that of the sweet potato counterpart. The blended starch bioplastic had the lowest tensile strength (1.175 MPa)

despite having the highest thickness (3.5×10^{-4} m). The blended bioplastic also has the lowest mechanical durability, limiting its use in rigid packaging materials.

These findings suggest that bioplastics generated from specific starch sources (cassava and sweet potato) are mechanically stronger than blended formulations and may, therefore, be more suitable for applications requiring greater mechanical durability and tensile resistance (Ismail et al., 2016). The relatively high degradability of sweet potato starch, combined with its robust tensile properties, suggests that it offers the dual advantage of strength and biodegradability. As observed by Boey and his group, such materials are suitable for packaging materials used in extreme conditions (Boey et al., 2022). The higher mechanical properties and its film-forming abilities are also attributable to its granular structure and low lipid-protein traces in sweet potato starch (Song & Zheng, 2008). As a result, the sweet potato film demonstrates superior load-bearing capacity. The lower tensile strength of the starch-blend bioplastic indicates its potential use in low-density packaging materials.

This study, however, did not investigate the influence of the plasticizer system or the v/v ratio of the plasticizer on the mechanical stability, structural, and environmental properties of the resulting bioplastic film.

Conclusion

This study examined the potential of starch-based bioplastics as alternatives to Petro-based, conventional synthetic polymers by evaluating their biodegradability and tensile strength. The bioplastic strips developed from cassava, sweet potato, and blend starches showed variability in biodegradability and mechanical strength. Bioplastic made from the starch blend showed 100 percent degradation efficiency in compost and a notable 61.53 percent in garden soil. However, its tensile strength (1.175 MPa) was the lowest. Sweet potato starch, under similar soil conditions, showed a 70 percent degradation efficiency in compost and 33.5 percent in garden soil, while exhibiting the highest tensile strength of 2.378 MPa. This bioplastic is suitable for rigid packaging applications. Cassava starch bioplastic showed the lowest degradability in both compost and garden soil, but with a moderate tensile strength—higher than that of the starch blend —due to its higher amylopectin content, which creates a branched structure that limits access by microbial enzymes.

This study has demonstrated that the biodegradability and mechanical properties of starch-based bioplastics are primarily influenced by the starch source and blend. To build on these findings, future work should investigate additional factors, such as composite materials, protein-starch combinations, soil microbial composition, and the concentration and type of plasticizer used.

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