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Design and Infrared Spectroscopic Study of Biodegradable Starch-Based Bioplastic

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ABSTRACT

The increasing environmental impact of conventional petroleum-based plastics has encouraged the development of sustainable and biodegradable alternatives. In the present study, starch obtained from natural sources such as potato and sweet potato was used for the synthesis of biodegradable starch-based bioplastics. The bioplastic films were prepared through a simple casting method using glycerol (propan-1,2,3-triol) as a plasticizer and hydrochloric acid as a catalyst, followed by neutralization with sodium hydroxide. The prepared materials were characterized using Fourier transform infrared spectroscopy (FTIR) to identify functional groups and confirm the formation of polymeric structures. The FTIR spectra showed characteristic absorption bands corresponding to O–H, C–H, C=O, and C–O functional groups, indicating the successful formation of polyester-type bioplastic materials. Mechanical properties were evaluated using tensile strength measurements, where sweet potato starch bioplastic exhibited higher tensile strength compared to potato starch bioplastic. Biodegradability was assessed through soil burial tests, which demonstrated significant degradation within a short period, confirming the environmentally friendly nature of the material. The results indicate that starch-based bioplastics derived from natural agricultural sources can serve as promising alternatives to conventional plastics. These materials offer advantages such as renewability, biodegradability, and reduced environmental impact, making them suitable for applications in packaging, agriculture, and disposable products.

1. Introduction

Bioplastics, also known as bio-based plastics, are polymers derived from renewable resources such as corn, potatoes, sugarcane, wheat, and vegetable oils. With the increasing environmental concerns related to conventional petroleum-based plastics and the depletion of fossil fuel resources, researchers are focusing on sustainable and eco-friendly alternatives [1-4]. Among the various renewable materials, starch has gained considerable attention due to its natural abundance, biodegradability, and low cost [5].

Conventional plastics are synthetic macromolecules derived primarily from petroleum resources, such as polyethylene, polyvinyl chloride (PVC), polystyrene, and polyethylene terephthalate (PET). These materials are highly durable and resistant to natural degradation processes, resulting in the accumulation of plastic waste in landfills and natural ecosystems [6]. As a result, plastic pollution has become a major environmental challenge worldwide. Early attempts to address plastic pollution involved the development of photodegradable plastics, which degrade when exposed to ultraviolet radiation. However, these materials only degrade under specific environmental conditions and do not fully solve the problem of plastic accumulation [3]. Therefore, recent research has focused on the development of bio-based and biodegradable plastics produced from renewable resources.

Examples of such materials include polyhydroxyalkanoates (PHAs), which are synthesized by microorganisms through fermentation processes, and polylactic acid (PLA), which is derived from agricultural feedstocks such as corn and sugarcane [7, 8]. Although these materials exhibit biodegradability and good material properties, their production costs remain relatively high, limiting their widespread commercial applications. Starch-based bioplastics provide an attractive alternative because starch is widely available, inexpensive, biodegradable, and easy to process [7]. However, native starch possesses certain limitations such as low mechanical strength, brittleness, and high sensitivity to moisture. To overcome these drawbacks, starch is commonly blended with plasticizers such as glycerol, reinforced with other biodegradable polymers, or chemically modified to improve flexibility and durability [9,10].

The development of starch-based bioplastics is closely associated with the concept of a circular economy, which emphasizes the use of renewable resources, reduction of environmental pollution, and sustainable waste management practices [11].

Therefore, this research continued research in starch-derived biodegradable plastics can significantly contribute to reducing dependence on petroleum-based plastics and promoting environmentally sustainable material technologies.

2. Experimental Methods

2.1 Materials

Biodegradable starch-based bioplastics are sustainable materials synthesized from natural starch sources such as corn, potato, cassava, or rice. These polymers are widely studied as potential alternatives to petroleum-derived plastics due to their biodegradability, renewability, and lower environmental footprint.

In this study, starch was extracted from potato and sweet potato, which were procured from the local market at Bandar Pusat Tun Abdul Razak, Jengka, Malaysia. The extracted starch served as the primary raw material for the preparation of bioplastics.

The chemicals used in the synthesis process included:

- Hydrochloric acid (HCl) – used for hydrolysis and pH adjustment.
- Propan-1,2,3-triol (Glycerol) – used as a plasticizer to improve flexibility and processability of the bioplastic.
- Sodium hydroxide (NaOH) – used for neutralization and pH control during the preparation process.

All chemicals were of analytical grade and were obtained from Loba Chemie Pvt. Ltd. (India). Distilled water was used throughout the experiments to ensure the purity of solutions and avoid contamination.

2.2 Starch Extraction

To extract starch, 100 g of potato and 100 g of sweet potato were separately washed, peeled, and grated into fine particles. Each sample was mixed with 100 mL of distilled water and ground thoroughly using a mortar and pestle to obtain a uniform slurry (Fig. 1). The resulting mixture was filtered through a strainer into a clean beaker, separating the fibrous residue from the crude starch suspension (Fig. 2). The crude starch

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solution was subjected to centrifugation at 10,000 rpm for 1 minute. The pellet obtained was resuspended in 100 mL of distilled water and centrifuged again under the same conditions to improve purity. The process was repeated until a white starch pellet was obtained. The purified starch was then collected, dried in a hot-air oven at 50–60 °C, and stored in an airtight container for further use (Fig. 3).

Fig. 1 Crude potato and sweet potato solution

Fig. 2 Centrifuged crude potato and sweet potato solution

Fig. 3 White starch pellet

To prepare starch-based bioplastic, synthesis of starch-based bioplastic 2.5 g of purified starch was dispersed in 25 mL of distilled water in a clean beaker. To this solution, 2 mL of hydrochloric acid (HCl) and 2 mL of propan-1,2,3-triol (glycerol) were added. The mixture was heated gently for 15 minutes with a watch glass covering the beaker to minimize water evaporation. After heating, the mixture was neutralized by adding sodium hydroxide (NaOH) solution dropwise until the pH reached neutral. The homogenized solution was then poured into sterile petri dishes and evenly spread using a glass rod to form uniform films. The films were allowed to dry in a laminar air flow chamber for 48 hours. After drying, flexible plasticized starch sheets were obtained (Figs. 4 and 5) and carefully removed for further characterization.

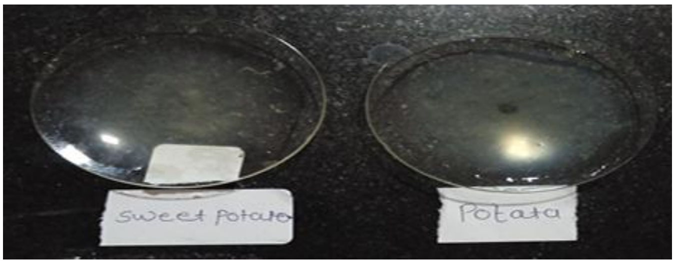

Fig. 4 Starch pellet of sweet potato and potato

Fig. 5 The starch based polyester synthesized from (a) potato and (b) sweet potato

2.3 Characterization

Perkin Elmer FTIR spectrophotometer (4000–400 cm^{-1}) was used to identify functional groups to confirm the type of plastic formed. Thermogravimetric studies (SDT Q600) under nitrogen were performed in the 30–500 °C range with a heating rate of 20 °C/min to determine thermal stability. Mechanical properties were measured using a Universal Testing Machine (Instron 5569). Samples (80 mm × 20 mm strips) were tested at a crosshead speed of 2 mm/min to evaluate compressive strength. Biodegradability was assessed by soil burial tests. Samples were weighed, buried for one week, and re-weighed to determine weight loss.

3. Results and Discussion

3.1 FTIR Spectroscopy

The FTIR spectra of sweet potato and potato bioplastics are presented in Fig. 6. Both spectra exhibited the presence of four major absorption peaks, namely O–H stretch C–H stretch C=O stretch C–O stretch. For potato O–H, C–H, C=O and C-O stretching frequency observed at 3425, 2932, 1655 and 1041 cm^{-1}and for sweet potato O–H, C–H, C=O and C-O stretching frequency observed at 3430, 2929, 1649 and 1026 cm^{-1}. The absorption peaks observed for each type of bioplastic are summarized in Table 1. From this analysis, it can be concluded that the type of plastic synthesized in this study is polyester, as evidenced by the presence of these four functional groups.

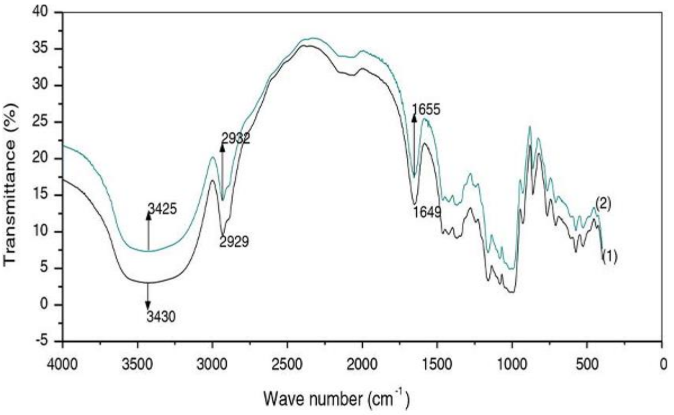

Fig. 6 FTIR spectra of starch-based bioplastics derived from (1) sweet potato and (2) potato

Table 1 The main FTIR absorption peaks (wavenumber, cm^{-1}) for potato and sweet potato starch-based bioplastic

Functional group	Potata	Sweet potato
O–H	3425 cm^{-1}	3430 cm^{-1}
C–H	2932 cm^{-1}	2929 cm^{-1}
C=O	1655 cm^{-1}	1649 cm^{-1}
C–O	1041 cm^{-1}	1026 cm^{-1}

3.2 Thermogravimetric Analysis (TGA/SDT Q600)

Thermogravimetric analysis was performed using SDT Q600 to evaluate the thermal stability and degradation behaviour of the starch-based bioplastic. The TGA curve exhibited a three-stage degradation pattern:

1. First Stage (30–150 °C): A minor weight loss (~5–10%) was observed, attributed to the evaporation of moisture and loosely bound water molecules due to the hydrophilic nature of starch.
2. Second Stage (200–350 °C): The major decomposition phase occurred with significant weight loss (~60–70%). This corresponds to breakdown of glycosidic linkages Decomposition of starch backbone (amylose and amylopectin)
3. Third Stage (350–500 °C): Further gradual weight loss (~10–20%) was associated with carbonization and decomposition of residual organic matter.

The thermal degradation profile confirms that the material is thermally stable up to ~200 °C, making it suitable for low-temperature processing applications. The presence of plasticizers (e.g., glycerol) reduces thermal stability slightly by weakening intermolecular hydrogen bonding. Compared to conventional plastics, the bioplastic shows lower degradation temperature, which is beneficial for biodegradability but limits high-temperature applications.

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3.3 Mechanical Properties

Mechanical testing was conducted to evaluate tensile strength, elongation at break, and Young's modulus. The moderate tensile strength indicates that the bioplastic is suitable for packaging and low-load applications. Biodegradability Study The rapid degradation is due to hydrophilic nature of starch microbial enzymatic activity (amylase enzymes). Sweet potato starch bioplastics offer superior mechanical strength and durability. Both materials demonstrate rapid and significant biodegradation, making them environmentally sustainable alternatives to conventional plastics.

4. Conclusion

The present study demonstrates the successful preparation and characterization of biodegradable starch-based bioplastics derived from potato and sweet potato starch. The synthesis process using glycerol as a plasticizer produced flexible bioplastic films through a simple and environmentally friendly method. Fourier transform infrared spectroscopy (FTIR) analysis confirmed the presence of characteristic functional groups such as O–H, C–H, C=O, and C–O, indicating the formation of polyester-type bioplastic structures. Mechanical analysis revealed that sweet potato starch bioplastics exhibited higher tensile strength compared to potato starch films, suggesting improved structural integrity. The soil burial biodegradation test further confirmed the eco-friendly nature of the materials, as both samples showed significant degradation within a short period.

Overall, the results highlight that starch obtained from natural sources can serve as an effective raw material for the development of sustainable plastic alternatives. Although some limitations such as moisture sensitivity and moderate mechanical strength still exist, the incorporation of plasticizers and further modification strategies may enhance their performance. Therefore, starch-based bioplastics represent a promising solution for reducing environmental pollution caused by conventional petroleum-based plastics and contribute to the advancement of sustainable material technologies.

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