engineering proceedings

MDPI

Proceeding Paper

Synthesis and Characterization of Starch-Based Bioplastics: A Promising Alternative for a Sustainable Future †

R. Anitha [1,*], K. Jayakumar [2], G. Vijay Samuel [1], M. Esther Joice [1], M. Sneha [1] and D. Sathya Seeli [3]

[1] Department of Biotechnology, Hindustan Institute of Technology and Science, Padur, Chennai 603103, Tamil Nadu, India; gvijays@hindustanuniv.ac.in (G.V.S.); mosesmestherjoice@gmail.com (M.E.J.); 21107019@student.hindustanuniv.ac.in (M.S.)

[2] Department of Mechanical Engineering, Sri Sivaubramaniya Nadar College of Engineering, Kalavakkam, Chennai 603110, Tamil Nadu, India; kjayakumar@ssn.edu.in

[3] Department of Chemistry, Hindustan Institute of Technology and Science, Padur, Chennai 603103, Tamil Nadu, India; dsathyas@hindustanuniv.ac.in

* Correspondence: ranitha@hindustanuniv.ac.in

† Presented at the International Conference on Processing and Performance of Materials, Chennai, India, 2–3 March 2023.

Abstract: With over 9 million additional tons of plastic waste entering the oceans each year, 165 million tons of plastic waste have already defiled our oceans. Considering that just 9% of plastic is recycled, the rest of the waste contaminates the environment or is dumped in landfills, where it can take up to 500 years to degrade while releasing hazardous chemicals into the soil. The bioplastics prepared in this study were obtained from tapioca and sweet potato using plasticizers like glycerol in various combinations. The biodegradability and mechanical and physical properties were analyzed. The tensile strengths of the prepared bioplastic films were 4.25 and 2.35 MPa with elongation at break (EAB) of 39.5% and 25.4% for tapioca and sweet potato bioplastics, respectively. The biodegradability of the films was examined, and thus, the obtained bioplastics in the study are shown to be a good alternative to the existing plastics.

Keywords: tapioca and sweet potato; biodegradability; SEM analysis; bioplastic film; XRD; water absorption percentage

Citation: Anitha, R.; Jayakumar, K.; Samuel, G.V.; Joice, M.E.; Sneha, M.; Seeli, D.S. Synthesis and Characterization of Starch-Based Bioplastics: A Promising Alternative for a Sustainable Future. *Eng. Proc.* **2024**, *61*, 30. https://doi.org/10.3390/engproc2024061030

Academic Editors: K. Babu, Anirudh Venkatraman Krishnan and M. Dhananchezian

Published: 5 February 2024

1. Introduction

Starch has demonstrated the potential to produce biodegradable materials because it is a cheap raw material that is readily available and renewable [1,2]. Also, it contains both branched and liner polymers such as amylopectin and amylose, respectively. Due to its double helical crystallographic structure, starch can endure extreme heat and shear [3]. Hence, with the use of alternative plant-based resources, it is possible to enhance the qualities of starch-based biodegradable polymers [4]. In the present study, starch-rich vegetable crop plants like cassava and sweet potato have been exploited for the preparation of bioplastics. Both are widely prevalent in many tropical and subtropical locations, including India, Bangladesh, and other Asian countries. The starch content of tapioca and sweet potato is 17% and 43.5%, respectively [5]. Both plants have high amylose content (17–43.5%) and a high gelatinization temperature (69–80%), minimal fat content, increased temperature as well as pulp viscosity, and reduced pulp breakage compared to the gels made from other starches [6,7]. Therefore, the present study demonstrated the production and characterization of starch-based bioplastics from tapioca and sweet potato developed using glycerol; this starch has characteristics compatible with produce films and minimum reports found so far on the production and characterization of these supplies.

2. Materials and Methods

2.1. Preparation of Starch and Bioplastic

Fresh sweet potato and starch tubers were cleaned, de-skinned, and cut into roughly 1 cm cubes and crushed at a high speed for five minutes. Starch was extracted as described by Syaubari et al. (2018) [8]. The sweet potato and cassava starch were added with 3 volumes of water to its weight and broken down into small pieces to obtain a slurry. The extract was then passed through a muslin cloth and then filtered, and it was dried to obtain a fine powder. A 5% cassava and sweet potato starch (w/v) was prepared; this was then mixed with a magnetic stirrer at 900 rpm for 5 min. Different concentrations of glycerol were then added to this mixture (1.5%, 2%, 2.5%, 3%), and after that, the mixtures were swirled once more for five minutes at 900 rpm. It was then heated to a temperature of 80 °C for 45 min. The solution was then cooled and poured into a mold, then placed at ambient temperature (27 °C–30 °C) until fully dry, after which it was dried for 24 h at 50 °C in the oven [9]. The final thicknesses of the manufactured bioplastic films were measured using a digital micrometer (Ocean Digital Micrometer 0–25 mm, India, with the least count of 0.001 mm).

2.2. Tensile Strength (TS) and Elongation at Break (EAB)

TS was measured with a 50 Hz 3 Phase Twin Screw Tensile Tester (digital), PACORR, Universal Testing Machine (UTM), India, using standard ASTM D882-02 [10]. The bioplastic films were cut at a length of 165 mm and width of 13 mm with a gauge length of 50 mm, and then secured onto the loading unit. The tensile experiment was conducted at a testing speed of 1 mm/min for measuring the modulus. The ratio between the initial length and the changed length of the sample after breakage (application of external stress) was measured to find out the EAB of the films.

2.3. Scanning Electron Microscope Analysis (SEM) and X-ray Diffraction (XRD) Analysis

The surface morphology of the prepared bioplastic films was measured using the FEI Quanta FEG 200 (FEI Company, Hillsboro, OR 97124-5793 USA) High-Resolution Scanning Electron Microscope (HRSEM) with a beam current of 18 pA, at an acquisition time of 40 s; a working distance of 7.5–8.5 mm was employed in the microscope, with an acceleration voltage of 10 kV. To learn more about the crystallinity of the prepared cassava- and sweet-potato-derived bioplastic samples, XRD (Empyrean X-ray diffractometer, PANalytical, Almelo, The Netherlands) was performed. Using a Philips powder diffractometer with Cu K radiation (k = 0.154 nm), the samples' XRD patterns were captured. The spectra were captured at room temperature with a 2 h step of 0.02 at a scanning rate of 2 h/min. The degree measurements were set from 2θ = 10.01 to 90° with beam wavelengths of λ = 1.54.

3. Results and Discussion

3.1. Tensile Strength (TS) and Elongation at Break (EAB)

The TS and EAB are crucial parameters for determining a film's applicability since they demonstrate the film's capacity to maintain integrity under stress. The cassava bioplastic film (CBF) exhibited a TS value of 4.25 MPa and an EAB value of 39.5% (Figure 1). The augmented TS value was due to the presence of cassava starch, which greatly interacted with glycerol in the starch mixture, and they served as a filler, giving the film sturdiness and strength However, due to the low ductility of starch, the elongation strength of the CBF film was low. The TS value of the sweet potato bioplastic film (SBF) was 2.35 MPa and the EAB was 25.4%; this is due to the addition of glycerol, which greatly enhanced the mechanical properties of the film, leading to the flexibility of the films in both cases (Figure 1). Hence, in both films, the EAB value improved because of the modest TS value. However, the SBF was softer and more flexible when compared to the CBF. Tensile strength decreased because of glycerol, reducing the density of the polymeric chains' structure [11].

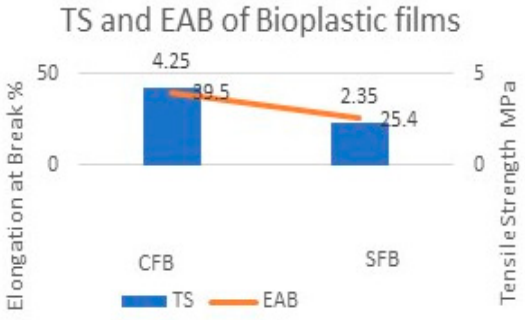

Figure 1. TS and EAB of the bioplastic films.

3.2. Scanning Electron Microscopic Analysis (SEM)

The surface morphology of the produced bioplastic sheets was investigated using SEM (Figure 2). Both the films had some cracks on their surface, which may be due to their brittle nature (Figure 2b). SBF was observed to have a smooth surface with some microvoids, which may be due to the degree of dispersal of the glycerol in the polymer milieu (Figure 2b). The CBF also had some minor voids; however, it exhibited a better incorporation of glycerol (Figure 2c). The long chains of starch's hydrogen bonds broke down during the gelatinization process, allowing water molecules to enter the hydroxyl group of the starch molecules, creating voids and microvoids. The surface morphology of the prepared CBF and SBF had comparable morphology with that of the used polyethylene elastic material reported by Gere et al. (2018) [12].

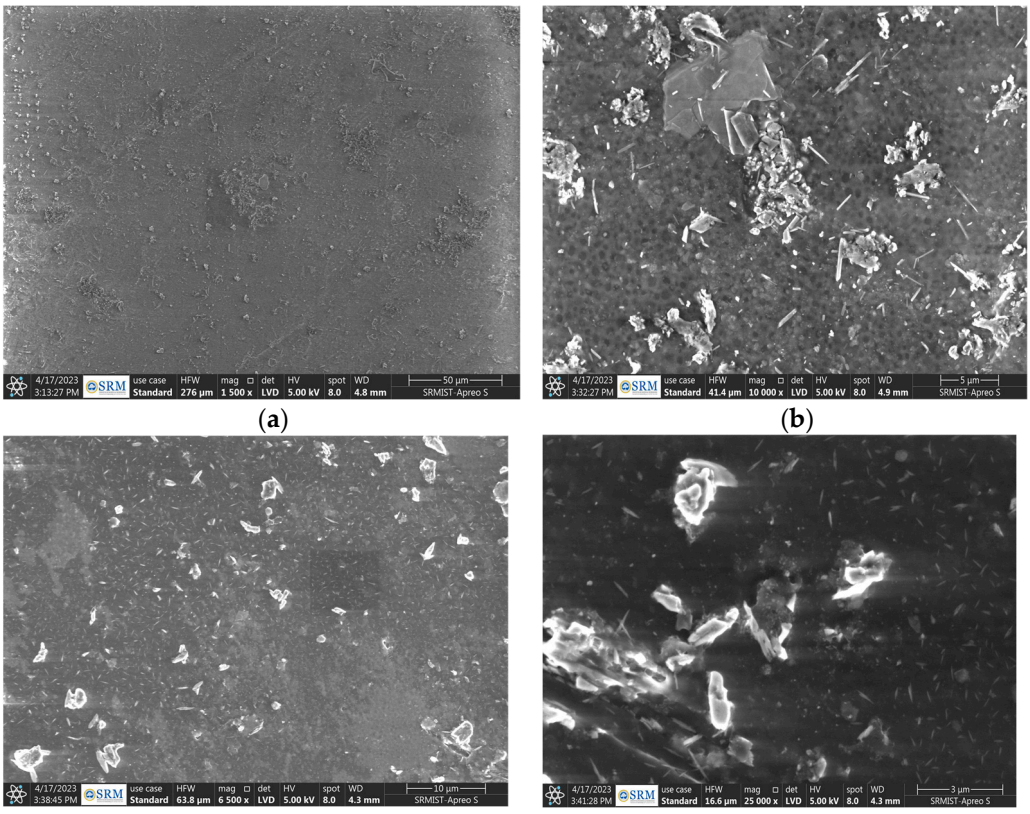

Figure 2. SEM images of (**a**) cassava bioplastic with 500×, (**b**) cassava bioplastic with 10,000×, (**c**) sweet potato bioplastic with 500×, (**d**) sweet potato bioplastic with 25,000×.

3.3. X-ray Diffraction (XRD) Analysis

The XRD pattern of sweet potato starches is shown in Figure 3a. The starches were allocated into types A to C according to their XRD patterns. Type C starch comprised type A and B crystallinities and could be sub-classified as CA, CC, and CB owing to the amounts of these crystallinities in it. Type CC starch had characteristic diffraction peaks at 15°, 17°, and 23° 2, and CA type starch had shoulder 2θ diffraction peaks at about 22° and 24°. The above diffraction pattern of sweet-potato-derived bioplastic showed broad peaks corresponding to 15° and 17°, which shows the CC type starch and semi-crystalline nature of sweet-potato-derived bioplastic, A shoulder peaks at about 22° reveals the presence of CA type. The results also showed that different types of starch exhibited XRD patterns with different diffraction angles and intensities [13]. The XRD pattern for cassava-derived bioplastic is shown in Figure 3b. The diffraction peak around 22.6° in the above graph is attributed to the typical crystal lattice of cassava-derived bioplastic, indicating the diffuse characteristics pattern of an amorphous phase. The produced bioplastic exhibits a sharper and narrower 2θ diffraction peak at 22.6 with a higher degree of crystallinity and higher tensile strength. It is noted that the two bioplastics are found to have identical characteristic diffraction peaks of about 22.6 and 44.3, with a slight difference in intensity.

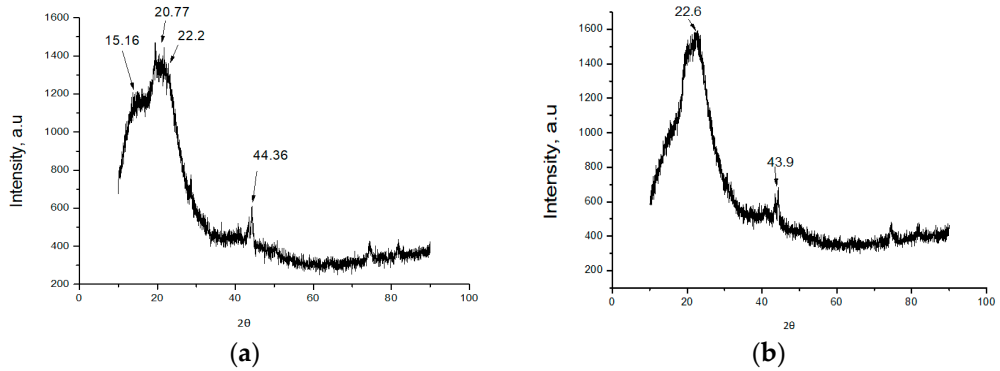

Figure 3. X-ray diffraction pattern of (**a**) sweet-potato-derived bioplastic; (**b**) cassava-derived bioplastic.

4. Conclusions

The present study was carried out in order to synthesize environmentally friendly and low-cost bioplastics derived from agricultural materials. Two different bioplastic films were prepared using different starch sources with glycerol and water. Each film exhibited various properties in terms of firmness and tensile strength. The films' mechanical, biological, and physical properties were examined. Based on the characterization results obtained in the study, it is evident that the CBF has given good results; hence, there is a possibility to obtain sustainable bioplastic from agricultural materials, which can aid as eco-friendly and low-cost alternatives to synthetic single-use plastics.

Author Contributions: Conceptualization, supervision, project administration, writing—review and editing, R.A.; visualization, software and validation, K.J.; methodology, G.V.S.; investigation, data curation and writing—original draft preparation, M.E.J., M.S. and D.S.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data sharing is not applicable.

Conflicts of Interest: The authors declare no conflicts of interest.

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