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Microstructural and Spectroscopic Analysis of Sweet Potato Starch Bioplastics Reinforced with Activated Carbon Using Scanning Electron Microscopy

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Abstract

The annual production of petroleum-based plastics releases hazardous gases, including carbon dioxide, which negatively impacts the environment. This study focuses on producing bioplastic using sweet potato starch as the main raw material, with activated carbon as a promising additive for enhancing starch-based biomaterials. A scanning electron microscope (SEM) was used to analyze the bioplastic samples, providing high-resolution imaging that is valuable for evaluating surface fractures, flaws, and contaminants. SEM analysis revealed that the morphological properties of the samples with and without activated carbon did not show significant differences in appearance, though voids, holes, and cracks were observed as flaws. The inclusion of activated carbon improved the bioplastics' capacity to absorb moisture and enhanced their porosity and tensile strength. By using renewable materials like sweet potato starch and additives like activated carbon, this study aims to develop sustainable alternatives to conventional plastics, reducing environmental impact and promoting eco-friendly materials in various industries.

Keywords: Scanning Electron Microscopy, bioplastic, surface morphology, voids, activated carbon, glycerin

Introduction

Plastics are essential in both industry and household products, used widely in items like luggage, bottles, toys, food packaging, and electronic components. However, the annual production of over 300 million tons of petroleum-based plastics releases hazardous gases, including carbon dioxide, which negatively impacts the environment. These plastics, such as low-density and high-density polyethylene, are not biodegradable, resulting in over a billion tons of plastic waste that can take hundreds of years to decompose [1]. The rising proportion of plastics in municipal waste has led to efforts to reduce synthetic plastic use and promote bioplastics, which can help decrease reliance on fossil fuels and mitigate environmental damage.

Plastics play a crucial role in various applications, but their environmental impact has led to a growing interest in bioplastics. This study focuses on sweet potato starch-based bioplastics, using activated carbon as an additive to enhance their properties. A key aspect of this research involves investigating the microstructure of these bioplastics through Microscopy Analysis. A Scanning Electron Microscope (SEM) provides high-resolution imaging, allowing researchers to evaluate surface features such as fractures, flaws, contaminants, and corrosion [2].

The SEM analysis reveals that the morphological properties of bioplastic samples with and without activated carbon do not differ significantly in appearance, though voids, holes, and cracks are identified as flaws [3]. The use of activated carbon improves the bioplastics' capacity to absorb moisture and enhances their porosity and tensile strength. By examining these microstructural details, the study aims to understand better how additives like activated carbon can influence the overall performance and potential applications of bioplastics [4].

The research highlights the potential of bioplastics as sustainable alternatives to petroleum-based plastics, particularly in the packaging sector. SEM analysis is crucial in assessing the structural integrity and suitability of bioplastics for various uses. This approach helps ensure that bioplastics can meet industry standards for strength and durability while offering an environmentally friendly solution to the plastic waste problem.

Literature Review

The microstructure of a starch granule has evolved to meet a plant's own needs and is therefore much more complex. Starch is a polysaccharide produced by plants as a means of storing energy. It is stored intracellularly in the form of spherical granules, with 2e100 mm in diameter. Most commercially available starches are isolated from grains such as corn, rice and wheat, or from tubers such as potato and cassava [5]. The microstructural analysis of the bioplastics was carried out using a Scanning Electron

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Microscope (Hitachi S-4800). Two different samples, 0.5 cm2 in size, of each bioplastic were fractured after immersion in liquid nitrogen and randomly broken to investigate the surface of the samples. Cryo-fractured samples were mounted on aluminum stubs and fixed on the support using double-sided adhesive tape. Finally, samples were gold palladium coated and observed using an accelerating voltage of 10 kV and a working distance of 10 mm [6].

The morphology of the bioplastic samples was assessed using scanning electron microscope (Leo 1430 VP, Germany). Two small pieces of film were fixed, one in a perpendicular position and the other in a horizontal position, on the aluminum sample holder. Then the samples were gold sputtered in a metallizer (Balzers FDU 010) for 3 min, followed by scanning electron microscope analysis. SEM images were produced with a magnification of 8000 times. The films selected for analysis were those containing 4 and 12 g of starch at concentrations of 30 and 60% of glycerol: these values were selected because they were the minimum and maximum values of each variable that allowed the formation of non-brittle bioplastics. The images were recorded at an acceleration voltage of 20 kV [7].

Research Methodology

Materials

Sweet Potato Starch

Sweet potato starch is composed of two polysaccharides: amylose and amylopectin. Amylose is a linear molecule with α-1,4-linkages, while amylopectin is a branched molecule with α-1,6-linkages. Depending on the variety, amylopectin makes up 70% to 85% of the starch. According to Philippine crop production statistics, Central Visayas produced a total of 2,782.5 metric tons of sweet potatoes from April to June 2021 [8]. Sweet potato (Ipomea batata), a carbohydrate source, is abundant in tropical regions like the Philippines.

Glycerin

Glycerin is used as a plasticizer in starch-based biodegradable films [9]. Plasticizers enhance polymer chain mobility in starch films by reducing intermolecular forces and the glass transition temperature [10].

Activated Carbon

Activated carbon is a porous, carbonaceous adsorptive material with a complex structure of carbon atoms. It possesses both hydrophobic and hydrophilic properties [11]. Surface modifications, whether covalent or non-covalent, can alter hydrophilicity by introducing polar or nonpolar functional groups [12].

Production of Sweet Potato Bioplastic

The bioplastics will be composed of 10g sweet potato starch, 5 mL vinegar, 60 mL water, and other components, with each test sample containing a unique activated carbon ratio. There will be 6 samples per ratio, resulting in a total of 24 bioplastic samples to be tested for their water hydrophobicity properties. Data on the bioplastic changes will be documented.

Before cooking, the ingredients were thoroughly mixed and stirred until the mixture thickened and bubbled. After heating and spreading on the stove, the mixture was returned to the container. The samples were then baked repeatedly to remove moisture. Each sample was roasted at 125°C and rotated for three hours to ensure even baking on both sides. Figure 1 illustrates the study flow chart.

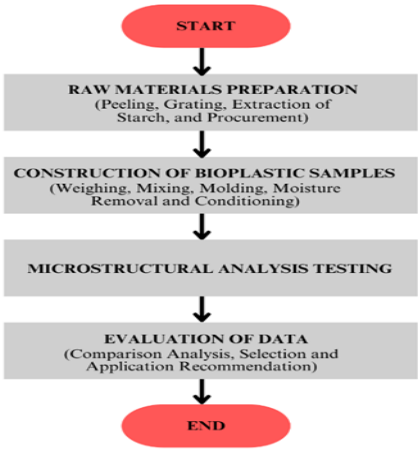

Figure 1. Project Study Flow Chart

Results

Scanning Electron Microscopy (SEM) was used to examine the surface microstructure of composites made of bioplastic. In this research, microstructural analysis of the samples will be analyzed using the Scanning Electron Microscopy available at the De La Salle Phenom Lab 1 – Nano Research Facility.

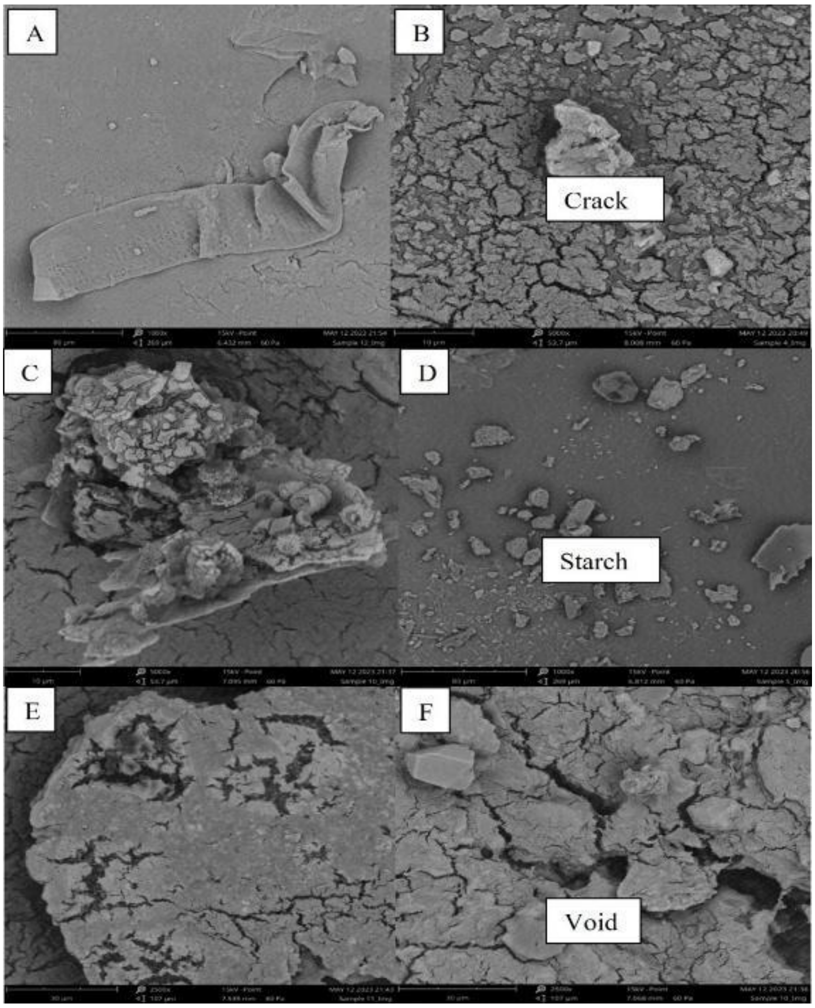

Figure 2. SEM Photograph of starch bioplastic (A) Starch Bioplastic (1000x), (B&E) Presence of cracks (5000x), (C) Presence of granules (5000x), (D) Starch Bioplastic (1000x), (F) Presence of void (5000x).

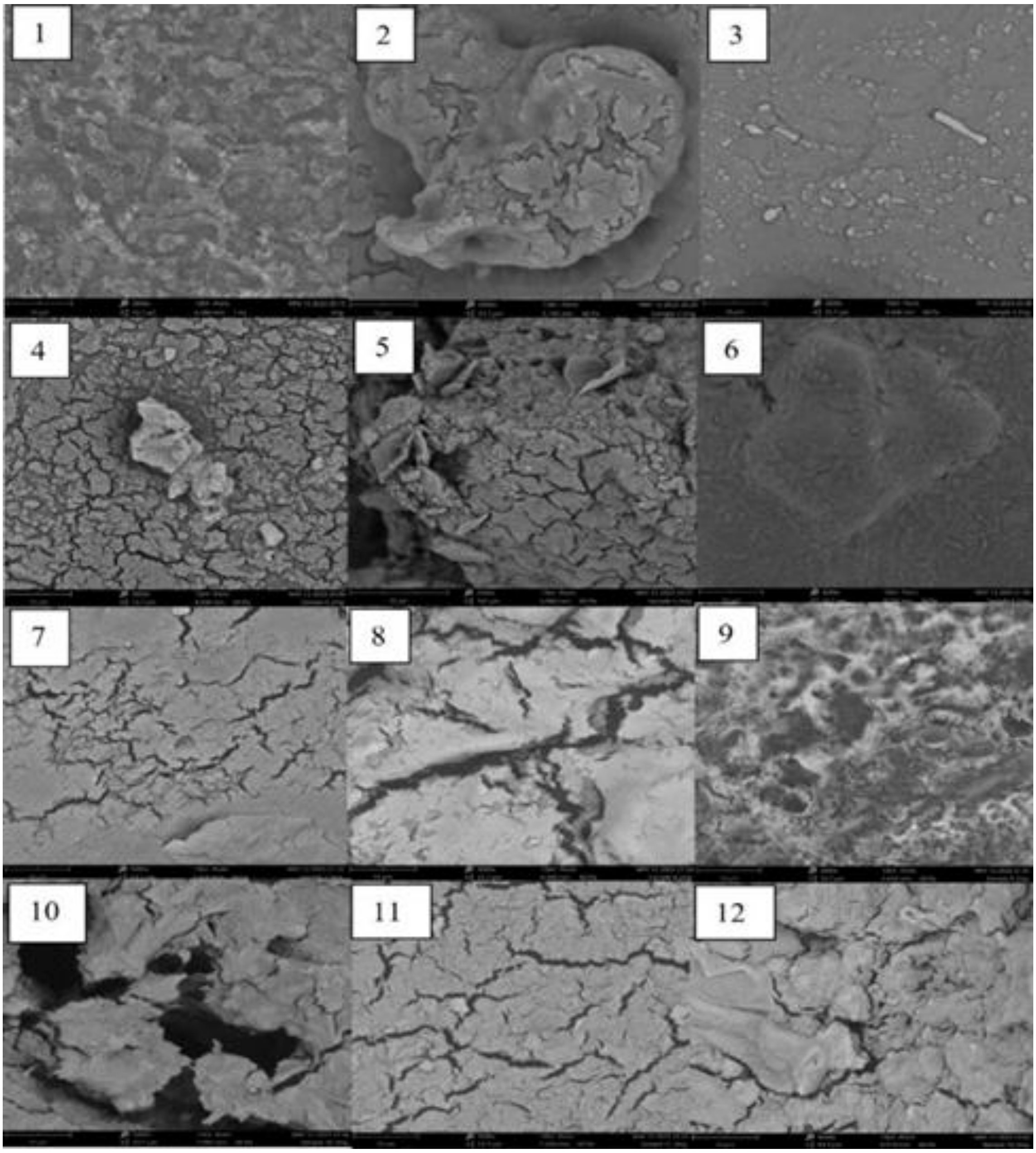

Figure 3. SEM photograph of starch bioplastic samples (1 to 3) 7mL glycerin with no activated carbon (5000x), (4 to 6) 11mL glycerin with no activated carbon (5000x), (7 to 9) 7mL glycerin with 0.4 activated carbon (5000x), (10 to 12) 11 mL glycerin with 0.4 activated carbon (5000x).

Discussion

Figure 2 above shows the bioplastic microstructure. It can be observed that the sample has uneven surface morphology, which can indicate that the mixture was not completely homogeneous during the sample preparation. These images show insoluble residues of swollen starch granules, which may greatly affect the final property of the starch bioplastic.

In Figure 3, the SEM images display the varying surface morphologies of samples with different glycerin and activated carbon contents. Most samples show fractures and voids, which can influence the final properties of the bioplastic. These cavities, fissures, and microcracks indicate that the sample blends may be incompatible. Activated carbon tends to repel water and other components in the bioplastic preparation, potentially leading to the microcracks observed in the SEM images. This behavior is attributed to the hydrophobic nature of activated carbon. Additionally, poor interfacial adhesion between the activated carbon and the starch matrix can result in microstructural defects, as illustrated.

The sample preparation process plays a significant role in the dispersion of the materials. One possible reason for the presence of microcracks and fissures on the surface of the bioplastic samples is the inhomogeneous dispersion of activated carbon. If this is the case, it could lead to areas on the surface with uneven stress distribution, which would ultimately affect the mechanical properties of the final bioplastic.

As shown in Figure 3, samples 1 to 5 are exhibiting fissures, micro-cracks, and coarse surface. Sample 6 has minimal micro-cracks and shape-irregularity. Samples 7 to 9 are again exhibiting micro-cracks and exhibits fissures. Sample 10 exhibits micro-cracks, large holes and have irregularity in surface morphology. Both samples 11 and 12 are exhibiting micro-cracks however, only sample 12 exhibits irregular surface morphology.

Based on the results of the SEM testing, the morphological property of the sample with non-activated carbon and with activated carbon does not have a great difference in appearance. The voids, holes and cracks are defects found in the results. The microstructure of the 12 samples were similarly alike as the activated carbon does not have distinct effect to the overall structure of the bioplastic composite.

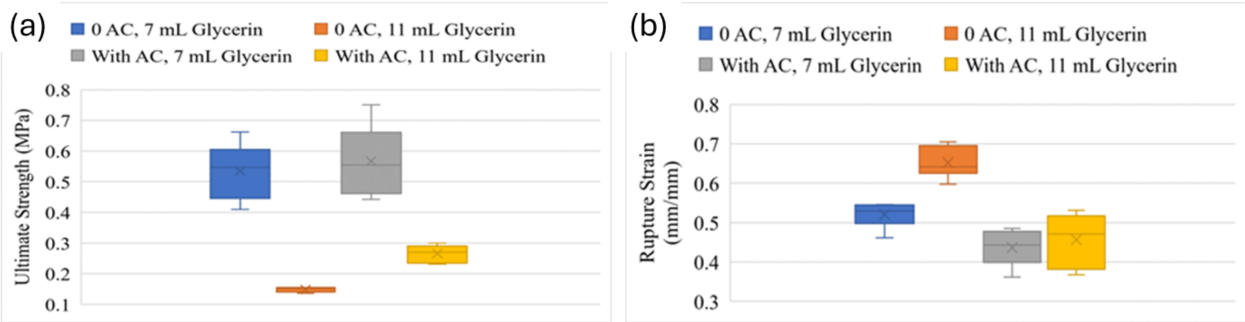

Figure 4. The ultimate strength and the rupture strain of the sample bioplastic composite.

Analysis of Figure 4 reveals that samples containing activated carbon displayed significantly lower rupture strain performance compared to those without activated carbon. In terms of ultimate strength, samples with 7 mL of glycerin performed better than those with 11 mL of glycerin. Furthermore, the incorporation of activated carbon has notably enhanced the hydrophobic properties of the starch bioplastic in this particular mixture.

Conclusions

In this study, we examined the microstructural properties of bioplastic composites using Scanning Electron Microscopy (SEM) to understand their surface morphology and tensile strength characteristics. The analysis revealed that the bioplastic samples exhibited notable granules, cracks, and voids on their surfaces, indicating incomplete homogenization during production and poor bonding between components. The SEM images demonstrated that the presence of these defects, such as fissures, micro-cracks, and irregular surface morphologies, is consistent across samples with varying glycerin and activated carbon content.

These structural imperfections suggest that the addition of activated carbon does not significantly alter the microstructural properties of the bioplastic, as both samples with and without activated carbon displayed similar defects. The study underscores the importance of improving the homogenization process and exploring alternative formulations or additives to enhance the structural integrity and performance of bioplastic composites. Overall, this research provides valuable insights into the microstructural challenges of bioplastic composites, highlighting areas for further improvement in material processing and formulation to achieve better mechanical properties and practical applications.

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