Upcycling Beer Bagasse into PLA-Bagasse Filaments for Sustainable 3D Printing

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ABSTRACT

This study explores the transformation of beer bagasse, a byproduct of the brewing industry, into a biodegradable composite material for 3D printing. The focus was on developing filaments by blending dried and milled bagasse with polylactic acid (PLA) and epoxidized soybean oil (ESBO) as a plasticizer. Multiple compositions were tested to evaluate the influence of bagasse and plasticizer ratios on the mechanical properties and printability of the final material. The optimal filament (80% PLA + 20% BG) was printed using a Creality Ender 3 V3, demonstrating the potential of upcycling agricultural waste into functional additive manufacturing materials.

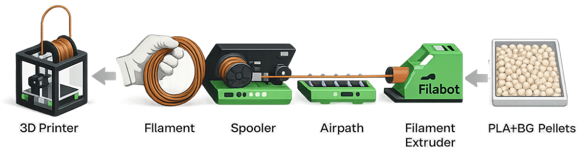
INTRODUCTION

Beer is one of the most commonly drank beverages and especially in Puerto Rico with a consumption in liters per capita of 67% in people aged 15 years or older for the year 2010, (NotiCel, 2014). This shows a growth in customer demand implying an ongoing growth in its production, causing a consequent increase in the fixed waste generated during its production. The most abundant beer waste is bagasse (spent brewers' grain), rising from the filtering and pressing of the malt obtained after the saccharification of the melted barley grain. Its composition is extremely variable, mostly due to the production process, raw materials, and industrial advancement. Several studies have evaluated the possibility of reusing beer bagasse for the recovery of energy, production and to produce bio-composites to be used in additive manufacturing techniques. With traditional manufacturing, the entire supply chain can take months and require an investment of millions or billions of dollars. Meanwhile, with additive manufacturing, much of the supply chain's intermediate steps are removed and at a faster time. This demonstrated that the correct use of additive manufacturing can have a strategic and positive impact on the economy and on environmental pollution, not only by reducing waste production, but also obtaining new products with high added value.

OBJECTIVES

- Develop a viable bio-based composite filament for 3D printing using brewer's grain and epoxidized soybean oil as a plasticizer.
- Identify optimal extrusion formulations by testing multiple pelletized mixtures and extrusion parameters.
- Evaluate the mechanical properties of the material, such as elasticity and stress resistance, and compare the properties of the material (PLA-BG) with a pure PLA filament.

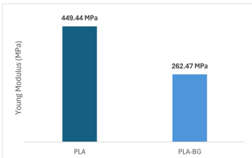
METHODOLOGY



DATA

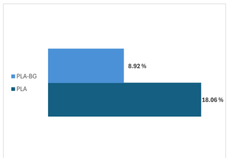
Mechanical Performance

Stiffness Retention



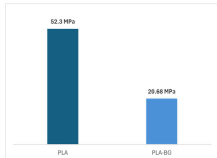
58% stiffness retained

Elongation at Break



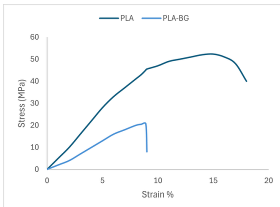
Composite preserves ductile behavior.

Tensile Strength



Structural performance maintained for non-load applications.

Stress-Strain Behavior Comparison



PLA-BG shows consistent elastic behavior with reduced peak stress, typical of natural-fiber composites.

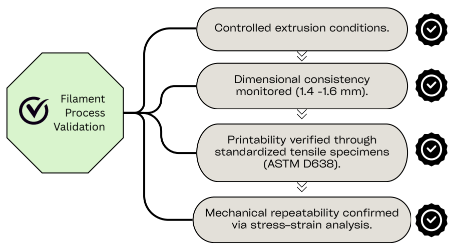


Figure 1. 20% agro-industrial waste successfully valorized into functional 3D printing filament.

ANALYSIS & RESULTS

The results demonstrated that the formulation of the PLA–bagasse bio composite strongly affected extrusion behavior, dimensional stability, and mechanical performance. The mixtures that contained epoxidized soybean oil (ESBO) exhibited high thermal sensitivity during extrusion, becoming excessively fluid and losing structural integrity, whereas the formulation with 80% PLA and 20% bagasse without the plasticizer achieved the most stable and continuous filament production, with satisfactory interfacial cohesion and good printability, and was therefore selected for mechanical testing. Tensile testing of this filament showed a progressive decrease in Young's modulus (68.95-41.37 MPa), ultimate tensile strength (1.24-0.90 MPa), and elongation at break (5.35-2.87%), which is attributed to the natural heterogeneity of the lignocellulosic filler and limited interfacial bonding between PLA and bagasse. The PLA alone demonstrated significantly higher stiffness, strength, and ductility, with a Young's modulus of 449.44 MPa, a tensile strength of 52.30 MPa, and an elongation at break of 18.06%, compared to the PLA-BG composite, which reached 262.47 MPa, 20.68 MPa, and 8.92%, respectively, confirming that the addition of agro-industrial waste leads to a reduction mechanical performance while maintaining adequate functionality for applications where sustainability is prioritized. Additionally, filament diameter variations (1.11-1.69 mm) indicated flow and cooling instabilities during extrusion, which directly affects material uniformity and mechanical behavior, highlighting the need for improved compounding and process control to enhance the overall performance of the bio composite filament.

CONCLUSIONS

This investigation demonstrated the feasibility of upcycling brewer's spent grain into a biodegradable PLA–BG filament for material extrusion 3D printing, providing a sustainable alternative to conventional polymers. The 80% PLA and 20% bagasse formulation without plasticizer showed the most stable extrusion, reliable printability, and adequate mechanical performance. Despite the composite exhibiting lower stiffness, strength, and ductility than PLA by itself, it maintained sufficient functionality for applications where sustainability and circular economy approaches take precedence over high load bearing capacity. The variations in filament diameter and tensile behavior indicate the need for improved filler dispersion and tighter process control to reinforce material uniformity. Overall, these findings highlight the potential of agro-industrial waste as a value-added resource for sustainable additive manufacturing.

FUTURE WORK

Future work should focus on improving the mechanical performance of the PLA-BG composite by optimizing particle size, dispersion, and interfacial bonding between PLA and BG. Further mechanical testing, along with microstructural and thermal analyses, is recommended to better understand structure–property relationships. Long-term degradation and printability behavior should also be assessed to determine the material's suitability for sustainable applications.

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