# Development and Mechanical Characterization of PLA-Based Biopolymer Composites Reinforced with Rice Husk and Wheat Straw for Sustainable Food Packaging Applications

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**Abstract: The environmental burden of petroleum-based plastics has necessitated the development of sustainable packaging materials. This study focuses on enhancing the mechanical properties of Polylactic Acid (PLA), a prominent biodegradable polymer, by reinforcing it with natural agro-waste fibers: rice husk (RH) and wheat straw (WS). The fibers were subjected to an alkaline peroxide pre-treatment to improve interfacial adhesion with the PLA matrix. Composites with varying weight percentages of PLA (90-100%), RH (0-6%), and WS (0-5%) were fabricated using melt-mixing and mould casting techniques. The mechanical properties, specifically compressive strength and Izod impact strength, were evaluated. The results demonstrated that the incorporation of treated fibers significantly improved the mechanical performance. The hybrid composite with 97% PLA, 2% RH, and 1% WS exhibited the optimum balance of properties, achieving a compressive strength of 68.12 MPa and an impact strength of 16.69 kJ/m², which represents an improvement over virgin PLA. This investigation confirms that rice husk and wheat straw are effective, low-cost, and sustainable reinforcements for developing high-performance PLA bio composites suitable for rigid and semi-flexible food packaging applications.**

**Keywords: Polylactic Acid (PLA), Rice Husk, Wheat Straw, Bio-composites, Mechanical Properties, Sustainable Packaging, Agro-waste.**

## I. INTRODUCTION

The escalating environmental concerns associated with the extensive use of non-biodegradable, petroleum-based plastics—particularly in food packaging—have prompted a global shift toward the development of sustainable alternatives [1]. Traditional plastics, while versatile and cost-effective, pose a significant threat to ecosystems due to their persistence in the environment [2]. In response, research efforts have increasingly focused on biodegradable polymers derived from renewable resources. Among these, Polylactic Acid (PLA) has emerged as a promising candidate owing to its commendable biodegradability, optical clarity, and satisfactory mechanical strength [3]. Sourced primarily from agricultural feedstocks such as corn starch or sugarcane, PLA offers a reduced carbon footprint, aligning well with the goals of the circular economy and environmental sustainability [4].

Despite its numerous advantages, PLA suffers from inherent limitations, including brittleness, low impact resistance, and relatively high production costs, which restrict its widespread application in demanding packaging scenarios. To address these shortcomings, reinforcing PLA with natural fibers has proven to be a promising strategy [5]. In particular, the use of agricultural residues like rice husk (RH) and wheat straw (WS) presents a dual advantage: mechanical enhancement of the polymer matrix and valorisation of agricultural waste [6]. These lignocellulosic fibers are abundant, renewable, and cost-effective, making them ideal candidates for eco-friendly composite development.

The integration of RH and WS into the PLA matrix has the potential to improve mechanical properties such as stiffness, tensile strength, and thermal stability [7]. These improvements stem from the rigid, fibrous structure of lignocellulosic materials, which can effectively bear mechanical loads when adequately bonded to the polymer matrix. However, a critical barrier to optimal performance lies in the inherent incompatibility between the hydrophilic nature of natural fibers and the hydrophobic PLA matrix [8]. This mismatch often leads to weak interfacial adhesion, compromising the overall mechanical integrity of the composite. Therefore, pre-treatment of the fibers, typically through chemical modification techniques such as alkali or silane treatments, is essential to enhance fiber-matrix bonding and ensure uniform dispersion within the polymer.

This study seeks to develop novel biocomposites by reinforcing PLA with chemically pre-treated rice husk and wheat straw fibers. By adopting a hybrid reinforcement approach, the research aims to synergistically combine the unique properties of both fiber types to achieve a balanced enhancement in material performance [9]. The primary focus lies in evaluating the compressive and impact strength of the developed composites, which are critical parameters for food packaging applications. The overarching goal is to produce a sustainable, high-performance material that not only reduces environmental impact but also contributes to waste minimization through the effective reuse of agricultural by-products [10].

## II. MATERIALS AND METHODS

### 2.1. Materials

Polylactic Acid (PLA) in granular form was used as the polymer matrix. Rice husk (RH) and wheat straw (WS) were collected from local agricultural sources. Analytical grade Sodium Hydroxide (NaOH) and Hydrogen Peroxide ($H_2O_2$) were used for the chemical pre-treatment of the fibers.

### 2.2. Pre-treatment of Fibers

The RH and WS were initially cleaned and dried. They were then subjected to an Alkaline Peroxide Pre-treatment (AHP) by immersing them in solutions of NaOH and $H_2O_2$ for 15 minutes each to remove lignin, hemicellulose, and silica. This process enhances the surface roughness and exposes more cellulose, improving bonding with the matrix [8]. The treated fibers were sun-dried for 24 hours and subsequently ground into a fine powder using a domestic grinder.

### 2.3. Composite Fabrication

PLA granules were melted in a stainless-steel container placed inside a muffle furnace at a temperature of 250°C. The pre-treated and pre-heated (50°C) RH and WS powders were added to the molten PLA in different weight ratios, as detailed in Table 1. The mixture was stirred mechanically to ensure a homogeneous dispersion of the fibers. The resulting composite melt was then poured into a greased ceramic mould and allowed to cool and solidify at room temperature, forming sheets of approximately 5mm thickness.

Table 1. Composition of fabricated PLA/RH/WS composites.

| Sample No. | PLA (wt.%) | Rice Husk (RH) (wt.%) | Wheat Straw (WS) (wt.%) |
|---|---|---|---|
| 1 | 100 | 0 | 0 |
| 2 | 95 | 5 | 0 |
| 3 | 95 | 0 | 5 |
| 4 | 97 | 2 | 1 |
| 5 | 94 | 4 | 2 |
| 6 | 90 | 6 | 4 |

### 2.4. Mechanical Characterization

The composite sheets were machined into standard test specimens.

Compressive Strength (CS) was tested according to ASTM D695 for rigid plastics using a Universal Testing Machine (FIE UTM 94100).

Izod Impact Strength (IS) was determined as per ASTM D256 (notched) using a Digital Izod/Charpy Impact testing machine.

## III. RESULTS AND DISCUSSION

The mechanical properties of the virgin PLA and its composites are summarized in Table 2.

Table 2. Mechanical properties of the fabricated composites.

| Sample No | Compressive Strength (MPa) | Impact Strength (kJ/m²) |
|---|---|---|
| 1 | 64.38 | 14.65 |
| 2 | 63.76 | 13.47 |
| 3 | 66.87 | 13.89 |
| 4 | 68.12 | 16.69 |
| 5 | 67.54 | 15.31 |
| 6 | 62.54 | 14.23 |

### 3.1. Analysis of Compressive Strength (CS)

Virgin PLA (Sample 1) exhibited a compressive strength of 64.38 MPa. The addition of 5% WS (Sample 3) increased the CS to 66.87 MPa, indicating that WS fibers effectively transferred stress within the PLA matrix. In contrast, Sample 2 (5% RH) showed a slight decrease in CS, suggesting potential fiber agglomeration or weaker interfacial bonding at this concentration. Notably, the hybrid composite (Sample 4) with 2% RH and 1% WS demonstrated the highest compressive strength of 68.12 MPa. This synergistic effect can be attributed to the improved fiber dispersion and effective interfacial adhesion achieved through chemical pre-treatment, which allows for efficient load transfer from the matrix to the fibers [7]. However, at higher total fiber loading (Sample 6: 10% reinforcement), the CS dropped to 62.54 MPa, likely due to fiber-fiber interaction, agglomeration, and the creation of stress concentration points.

### 3.2. Analysis of Impact Strength (IS)

The impact strength of virgin PLA was 14.65 kJ/m². Similar to the trend in CS, the hybrid composite (Sample 4) displayed a remarkable 13.9% improvement in impact strength, reaching 16.69 kJ/m². This enhancement indicates that the well-bonded RH and WS fibers can act as obstacles to crack propagation, absorbing more energy during fracture [9]. The combination of both fibers appears to create a more tortuous path for cracks, thereby increasing the toughness of the otherwise brittle PLA matrix. Samples with single-fiber reinforcement (2 and 3) showed a decrease in impact strength, which may be due to a less optimal fiber architecture for resisting impact loads.

## IV. CONCLUSION

This study successfully developed and characterized fully biodegradable composites from PLA reinforced with pre-treated rice husk and wheat straw. Chemically treated RH and WS act as effective reinforcing agents in a PLA matrix. A hybrid reinforcement strategy proved superior to single-fiber reinforcement. The optimal composition was identified as 97% PLA, 2% RH, and 1% WS. The optimized hybrid composite showed a significant improvement in both compressive strength (68.12 MPa) and impact strength (16.69 kJ/m²) compared to virgin PLA. The use of agro-waste not only enhances material performance but also contributes to a circular economy. The developed PLA/RH/WS composites demonstrate great potential for use in rigid and semi-flexible food packaging applications, offering a sustainable alternative to conventional plastics without compromising mechanical integrity. Future work will focus on evaluating other critical properties for packaging, such as thermal stability, water vapor barrier, and biodegradation rate.

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