DEVELOPMENT OF BIOPLASTIC FROM AGRICULTURAL RESIDUE (MORINGA OLEIFERA) FOR SUSTAINABLE FOOD PACKAGING APPLICATION

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Introduction:

Recent scientific research has increasingly focused on the use of natural fibres as environmentally friendly and biodegradable alternatives to conventional synthetic fibres such as glass and carbon. These natural fibres not only reduce environmental impact but also provide renewable and sustainable material sources (Faruk et al., 2012). In this context, bio-based nanocomposites were developed using cellulose as a filler via a water evaporation process (Lavoine et al., 2012). Considering the environmental impact of traditional packaging materials, biodegradable polymers are emerging as promising substitutes for food packaging applications. One such polymer, polylactic acid (PLA), is a synthetic biodegradable material that exhibits excellent flexibility when blended with plasticizers like glycerol. Moreover, it can be functionalized to exhibit antimicrobial properties (Auras et al., 2004; Avérous & Pollet, 2012).

In this study, PLA was incorporated with powdered *Moringa oleifera* leaves to explore its antibacterial and antifungal potential. The bioplastic films were prepared using the solution casting technique. Although bioplastics derived solely from plant leaf powder often exhibit suboptimal physicochemical properties, limiting their use in packaging applications, these limitations can be addressed by combining the plant material with synthetic biodegradable polymers and selected additives to enhance performance (Verdi et al., 2020).

The growing global demand for plastics, driven by rapid urbanization, industrialization, and population growth, has resulted in the unsustainable accumulation of non-biodegradable plastic waste. In light of these environmental challenges, biodegradable polymers represent a viable alternative to conventional plastics, especially in food packaging (Ranote et al., 2024).

The utilization of agricultural residues, such as *Moringa oleifera* (drumstick) leaves, for bioplastic production offers a dual benefit: reducing environmental pollution and adding value to agricultural byproducts. Enhancing the mechanical, thermal, and barrier properties of these bio-based plastics can lead to the production of higher volumes of functional biodegradable materials.

The primary objective of this study is to investigate the physical, chemical, and antimicrobial properties of bioplastics formulated using *Moringa oleifera* leaf powder, with the aim of advancing sustainable alternatives to traditional petroleum-based packaging materials.

Figure 1: Development of Bioplastic from *Moringa Oleifera.*

Objectives:

The primary aim of this study is to develop and evaluate biodegradable bioplastics derived from ***Moringa oleifera*** (drumstick) leaf powder and polylactic acid (PLA), with the broader goal of creating sustainable and environmentally friendly alternatives to conventional petroleum-based plastics. The specific objectives are outlined below:

<u>1. To develop a biodegradable and compostable bioplastic from agricultural residue</u>

This objective focuses on the utilization of agricultural residues, particularly *Moringa oleifera* leaves, for the development of bioplastics. The use of such natural materials contributes to the reduction of plastic waste and minimizes the environmental damage caused by conventional, non-degradable plastics. Upon disposal in the soil, the bioplastic is expected to degrade through microbial action, eventually transforming into compost that can enrich the surrounding soil and benefit plant growth. Enhancing the biodegradability of these materials also supports the circular economy by converting waste into valuable end products.

<u>2. To ensure cost-effectiveness and promote rural agricultural sustainability</u>

In the Indian agricultural context, many farmers face challenges due to limited income from crop production. By encouraging the cultivation of *Moringa oleifera*, which is a fast-growing and multipurpose crop, farmers can generate income from both drumsticks and their nutrient-rich leaves. This strategy not only ensures a sustainable supply of raw material for bioplastic production but also enhances the economic welfare of farming communities. Furthermore, the accessibility and affordability of the resulting bioplastic will make it a viable option for daily use among the general public.

<u>3. To enhance the mechanical and barrier properties of the bioplastic</u>

This objective aims to improve the functional characteristics of the developed bioplastic, such as tensile strength, flexibility, and barrier properties (e.g., resistance to moisture and gases). By incorporating cellulose fibres and optimizing the polymer blend, the study seeks to produce a thin film bioplastic that rivals or surpasses conventional plastic in mechanical performance. The enhancement of these properties is essential for ensuring the material's applicability in packaging and utility purposes, especially where durability and protective qualities are required.

Methodology:

The development of biodegradable bioplastics from Moringa oleifera leaves involved a series of systematic steps including the extraction of cellulose, isolation of plant extracts, preparation of the polymer matrix, film casting, and characterization of the resulting bioplastics. The detailed procedures are outlined below:

1. Extraction of Cellulose from Moringa oleifera Leaves

The extraction of cellulose from *Moringa oleifera* leaves was carried out through three major steps: alkaline treatment, bleaching, and acid hydrolysis, adapted from established protocols (Sun et al., 2004; Poletto et al., 2014).

Pre-treatment: Fresh Moringa leaves were washed thoroughly with distilled water to remove dirt and impurities, then dried in an oven at 50 °C overnight. The dried leaves were ground into a fine powder using a mechanical grinder.

Alkaline Treatment: The powdered leaf sample was soaked in an alkaline solution of sodium hydroxide (NaOH) to remove lignin and hemicellulose. The mixture was heated in a water bath at 60 °C for 2–4 hours. This treatment helps in delignification and partial removal of non-cellulosic polysaccharides.

Bleaching: The residue obtained after alkaline treatment was filtered and washed with distilled water until neutral pH was achieved. It was then subjected to bleaching using a hydrogen peroxide (H_2O_2) or sodium chlorite ($NaClO_2$) solution in acidic conditions and heated for approximately 2 hours to remove residual color and enhance purity.

Acid Hydrolysis: The bleached cellulose was then treated with a concentrated acid (e.g., sulfuric acid) to convert amorphous regions into crystalline cellulose. The mixture was boiled at controlled temperatures for 2–4 hours, followed by filtration and drying to obtain purified cellulose crystals suitable for polymer blending.

2. Isolation of Plant Extract

To obtain the bioactive extract, dried or fresh Moringa oleifera leaves were soaked in distilled water and maintained in a water bath at 60 °C for 2–3 hours. The solution was then filtered using Whatman No. 1 filter paper. The resulting aqueous extract was collected and stored for further incorporation into the polymer matrix. This extract may contribute antimicrobial properties to the bioplastic (Siddhuraju & Becker, 2003).

3. Preparation of Polymer Matrix

The polymer matrix was prepared by combining the extracted cellulose, PLA, and selected additives to enhance flexibility and film-forming properties.

- **Dissolution of Cellulose**: The cellulose obtained from the bleaching step (excluding acid-treated cellulose for improved flexibility) was dissolved in a solvent such as dimethyl sulfoxide (DMSO) or a dilute NaOH solution to enhance dispersion.
- **Polymer Blending**: The polymer solution was prepared by mixing PLA, glycerol (as a plasticizer), citric acid (as a crosslinking agent), cellulose, and the isolated Moringa extract. The entire mixture was stirred continuously using a magnetic stirrer for 2–4 hours at an elevated temperature to ensure homogeneous dispersion of all components (Auras et al., 2004).

4. Film Casting

After stirring, the polymer blend was poured into sterile Petri dishes to form thin films. These were left to dry at room temperature or in a controlled oven to allow solvent evaporation, resulting in the formation of bioplastic films. The thickness and uniformity of the films were maintained to ensure consistency during further testing.

5. Characterization

The prepared bioplastics will be subjected to various characterization tests to evaluate their:

- **Mechanical Properties** (tensile strength, elongation at break)
- **Flexibility and Elasticity**

- **Water Absorption Capacity**
- **Biodegradability in soil or compost conditions**
- **Barrier Properties** (resistance to moisture and oxygen)
- **Antibacterial and Antifungal Activity**

These tests were conducted following standard protocols such as ASTM D882 for mechanical testing and ASTM D5338 for biodegradability.

Result and Conclusion:

1. Physical Appearance

The bioplastic films obtained through the casting method were smooth, flexible, and translucent with a slight greenish brown tint due to the inclusion of *Moringa oleifera* leaf powder. No visible cracks or brittleness were observed in films containing up to 20% leaf content.

2. Mechanical Properties

The mechanical properties will be evaluated using a universal testing machine.

3. Water Absorption Test will be conducted
4. Biodegradability

Soil burial tests will be conducted for 30 days to detect biodegradability.

5. Antimicrobial Activity

Zone of inhibition tests will be carried out to detect antimicrobial property of synthesised bioplastic.

Conclusion

This study will aim to demonstrate the feasibility of producing biodegradable, flexible, and functionally enhanced bioplastic films using *Moringa oleifera* leaf powder and polylactic acid (PLA). The inclusion of agricultural residues such as *Moringa* is expected to add antimicrobial properties to the films and contribute to improved biodegradability. While the addition of plant powder alone may slightly reduce tensile strength, blending with cellulose fibers will be used to mitigate this effect and is anticipated to enhance mechanical performance.

These findings will highlight the potential of utilizing natural, locally available agricultural waste to develop sustainable alternatives to petroleum-based plastics—particularly in food packaging and related applications. Further optimization in formulation and large-scale production will pave the way for economically viable and eco-friendly packaging materials.

Future Scope:

This research focuses on the development and characterization of biodegradable bioplastics using Moringa oleifera leaf powder blended with polylactic acid (PLA). The intended applications and benefits of the resulting bioplastic materials are explored in various environmental and commercial contexts. The scope of the study includes:

1. Food packaging applications

One of the primary applications of bioplastics is in sustainable food packaging. The bioplastic developed in this study is expected to act as an effective barrier to moisture, oxygen, and microbial contamination, thereby preserving food quality and extending shelf life. PLA-based bioplastics have already been shown to be suitable for such applications due to their transparency, biodegradability, and mechanical properties (Siracusa et al., 2008).

2. Food wrapping to prevent contamination

The inclusion of *Moringa oleifera* leaf powder may provide natural antimicrobial activity, which can help prevent microbial contamination of food items during storage and transport. Moringa leaves are known for their high content of bioactive compounds with antibacterial and antifungal properties (Siddhuraju & Becker, 2003). This makes the bioplastic ideal for wrapping fresh produce, bakery items, and ready-to-eat food, enhancing both hygiene and food safety.

3. Utility based on material thickness

By adjusting the thickness of the bioplastic sheets during the fabrication process, their mechanical strength and flexibility can be tuned for various applications. Thinner films may be used for packaging lightweight goods, while thicker sheets can serve for carrying heavier items or forming containers. PLA's mechanical properties such as tensile strength and elasticity are modifiable with the addition of plasticizers and fillers (Auras et al., 2004), allowing for a wide range of use cases.

4. Biodegradability

A critical feature of this bioplastic is its environmental compatibility. PLA and other bio-based polymers are known to degrade under composting or soil conditions within a few months (Drumright et al., 2000). The addition of natural plant-based fillers like Moringa leaves may further enhance biodegradability, as they contribute to microbial breakdown and reduce the overall synthetic content of the composite.

5. Eco-friendliness and cost-effectiveness

The use of agricultural by-products such as *Moringa oleifera* leaves contributes to waste minimization and promotes the circular economy. This strategy not only lowers the production cost of bioplastics but also reduces dependence on petroleum-based plastics (Shen et al., 2009). As a result, these materials offer a cost-effective and eco-friendly alternative suitable for developing sustainable packaging solutions.

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