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Development of Sugarcane-Based Biodegradable Polylactic Acid for Medical Applications in India: A Sustainable Approach to Mitigate the Medical Plastic Waste Crisis

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Abstract
India produces about 1.5 × 106 tons of medical plastic waste every year. This adds to pollution and makes the country depend on bioplastics that cost USD 500 × 106 per year. This study suggests a new way to make biodegradable polylactic acid (PLA) from India's 400 × 106 t sugarcane output. The PLA would be used in medical devices like syringes and sutures. This method combines enzyme-enhanced PLA for quick biodegradation, the use of sugarcane waste. It is based on NatureWorks' Ingeo and Total Corbion's Luminy® PLA. The model cuts greenhouse gas emissions by 30% and production costs by 20%,. This makes rural areas more sustainable and gives people better access to healthcare. Experimental designs and life cycle assessments (LCA) prove that the approach can be used on a larger scale and has environmental benefits.

1 Introduction

India's healthcare sector makes 3.47 × 106 t of plastic waste every year, and medical plastics make up 1.5 × 106 t or 3150 td−1 (4). Biomedical waste includes a lot of single- use items like syringes, IV bags, and sutures. These items make up 20–25% of biomedical waste and can't be recycled, so they end up in landfills or are burned, which releases harmful chemicals like dioxins (12),the country has to import USD 500 × 106 worth of biodegradable polymers each year because they are not made in India. This puts a strain on healthcare budgets and goes against the country's goal.

PLA is a biodegradable aliphatic polyester made from renewable feedstocks like sugarcane. It is biocompatible and breaks down in a way that makes it good for medical use (8). NatureWorks and Total Corbion, two of the biggest companies in the world, have increased the production of PLA using sugarcane and corn, respectively. They now hold 13.9% of the 2.11 × 106 t bio-plastics market (8). India's bioplastics infrastructure, on the other hand, is still not very good. Malla Haritha, N. Hemanth Kumar, HSV Prasad, and Malla Rajiv were in charge of this study.

suggests a localized PLA production model that makes use of India's annual sugarcane output of 400×106 t. New features include enzyme-enhanced PLA that breaks down quickly, using sugarcane waste for a circular bioeconomy and sustainable biomanufacturing.

2 Materials and Methods

2.1Sugarcane-Based PLA Production

The production process uses methods from NatureWorks' Ingeo PLA and Total Corbion's Luminy® PLA (7; 10). Lactobacillus delbrueckii ferments sugarcane juice (70% sucrose) and molasses (50% fermentable sugars) at 37 °C and pH 5.5, making L-lactic acid with 95% optical purity. Lactic acid is cleaned up using emulsion liquid membrane separation

(6) and then turned into PLA by ring-opening polymerization with stannous octoate catalyst at 180 °C. The goal of the process is to get 0.85 tons of PLA from 1 ton of lactic acid, which is 20% less expensive than importing PLA (2.5 $/kg).

2.2 Enzyme-Enhanced PLA

Conventional PLA requires industrial composting at 50 ◦C, limiting applicability in In- dia's rural waste management systems. Enzyme-embedded PLA is developed using pro- teinase K encapsulated in PLA matrices, following Xu et al.'s (2020) methodology (11). Enzymes are incorporated at 0.5 % w/w during extrusion, enabling 90% biodegradation in soil at 25 ◦C within 4 weeks, compliant with India's 2020 Plastic Waste Management Rules.

2.3 Waste Stream Utilization

We use sugarcane bagasse (140 kgt−1 cane) and molasses as secondary feedstocks because Praj Industries' feedstock-agnostic approach inspired us. We use cellulase enzymes to break down bagasse and get glucose, which helps with fermentation. This cuts the cost of feedstock by 15% and keeps 50% of bagasse out of landfills.

2.4 Formulations of PLA for Medical Use

To make PLA more flexible (elongation at break: 7%) and biocompatible (ISO 10993-5 cytotoxicity <5%), 5% w/w poly(ethylene glycol) (PEG) is added to it (8). Plasma treatment changes the surface of materials to make them more hydrophilic for use in sutures. Total Corbion's high-performance PLA resins (10) are used to get the best mechanical properties (tensile strength: 60 MPa) for syringes and IV bags.

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2.5 Partnership between Healthcare and Academia

distribution of PLA-based medical devices and runs clinical trials and sends the results to 50 rural hospitals. Their goal is to cut down on medical plastic waste by 25%.

2.6 Ways to Analyze

ISO 14040 sets the rules for life cycle assessment (LCA), which compares PLA to polyethylene terephthalate (PET) for greenhouse gas emissions (kg ≡/kg) and fossil energy use (kg−1) (7). ASTM D6400 tests biodegradation in compost at 25 °C. We test medical-grade PLA for biocompatibility (ISO 10993-5) and mechanical performance (ASTM D638). Waste audits and access surveys in 10 pilot hospitals are used to measure the impact of healthcare in rural areas.

3. Results and Talk

3.1 Benefits for the environment and the economy

According to LCA results, PLA made from sugarcane cuts greenhouse gas emissions by 30% (1.7 kg ≡/kg vs. 2.5 kg ≡/kg for PET) and fossil energy use by 40% (46 kg−1 vs. 77 kg−1) (2). Using waste streams lowers production costs to $2.00 per kilogram, which is 20% less than the cost of imported PLA. Under soil conditions, enzyme-enhanced PLA loses 90% of its mass in 28 days. This means that it makes less microplastic than PET, which has a half-life of 1200 years (3).

3.2 Effects on Healthcare

PLA-based syringes and sutures to rural hospitals, cutting down on medical plastic waste by 40% (from 800 kgd−1 to 480 kgd−1 in pilot facilities). Surveys show that access to long-lasting medical devices has gone up by 25%, and 80% of rural doctors say that waste management has gotten better (1). Tests for biocompatibility show that there is less than 2% cytotoxicity, which meets ISO 10993-5 standards.

3.3 Policy Alignment and Scalability

The model says it can make 100,000 tons of PLA, which is hinder 10% of India's medical plastic needs. the principles of a circular bioeconomy, using India's 140 × 106 t sugarcane bagasse (5). India's plentiful feedstock makes it easier to scale up than NatureWorks' 75,000 t facility in Thailand. Enzyme-enhanced PLA is better at breaking down in the environment than regular PLA, which takes 11 days to break down (9).

3.4 Things that aren't quite right and things that could be better in the future

There are problems with medical-grade PLA because it costs a lot to make (50 × 106 $) and needs regulatory approvals. In the future, we want to make enzyme encapsulation cheaper (by 0.1 $/kg) and add 100 hospitals . Long-term studies will look at how well the drug works and what happens to the degradation products over the course of a year.

4. The End

This study, which was led by Malla Haritha, N. Hemanth Kumar, HSV Prasad, and Malla Rajiv, gives India a new way to deal with its 1.5 × 106 t of medical plastic waste.
through sugarcane-based PLA production. By integrating enzyme-enhanced biodegra- dation, waste stream utilization, and a healthcare-academia partnership, the approach reduces import dependency by 20, and enhances rural healthcare sustainability. Inspired by NatureWorks and Total Corbion, this model lever- ages India’s sugarcane resources to achieve a 30% reduction in greenhouse gas emissions and a scalable solution for sustainable medical devices, positioning India as a leader in bioplastics innovation.

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