

# Development of Sugarcane Bagasse-Based Biodegradable Sanitary Pads for Sustainable Menstrual Hygiene Management

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**Abstract**—Menstruation is a natural physiological process that begins at puberty and requires access to safe and hygienic menstrual products. However, most commercial sanitary pads contain large amounts of non-biodegradable plastics and synthetic polymers, creating substantial environmental challenges. Green biotechnology offers promising solutions through the development of sustainable, bio-based alternatives derived from renewable resources. In this study we represents a biotechnological approach to producing biodegradable sanitary pads using sugarcane bagasse waste an abundant lignocellulosic by-product of the sugar industry. We report a simple approach for developing biodegradable menstrual hygiene pads, which converting agricultural waste into a functional absorbent biomaterial through eco-friendly processing. In this study we standardized a simple protocol for biopads using Bagasse fibers were extracted, purified, and mechanically refined to enhance porosity and fluid retention. In addition natural bio-derived materials including cotton, gelatin, muslin cloth and biodegradable bioplastics were incorporated to improve absorption efficiency, antimicrobial potential, comfort, and structural integrity. Further the prototype pads were evaluated for absorbency, retention capacity, pH neutrality, comfort, thickness, and biodegradability. The preliminary results demonstrate that sugarcane bagasse-based pads achieve competitive absorbency while decomposing significantly faster than commercial pads. The findings of our study emphasize that lignocellulosic biomass can be effectively transformed into value-added bioproducts through simple, scalable processing techniques. Therefore our work underscores the potential of biotechnology in waste valorization, offering an environmentally responsible, low cost alternative to synthetic menstrual products. The study

supports the feasibility of large-scale production of biodegradable sanitary pads, contributing to sustainable menstrual health management, reduced plastic pollution, and enhanced circular bio economy practices.

**Index Terms**—Bio-based materials, Biodegradable sanitary pads, Menstrual hygiene Sugarcane bagasse, Sustainable biotechnology, Waste valorization.

## I. INTRODUCTION

Menstrual hygiene is a fundamental component of women's reproductive health, dignity, and overall well-being. Safe menstrual hygiene management (MHM) is essential to prevent reproductive tract infections (RTIs), maintain genital health, and promote psychosocial comfort during menstruation [1]. Inadequate menstrual hygiene practices have been associated with an increased risk of urogenital infections, irritation, school and workplace absenteeism, and reduced quality of life [2&3]. In many developing regions, limited access to affordable and hygienic menstrual absorbents remains a significant public health challenge. There are limited studies on Indian adolescent girls have highlighted common menstrual morbidities, gaps in awareness, and the need for improved educational interventions and access to safe absorbent materials to enhance menstrual health outcomes [4&5]. Therefore, ensuring access to safe, affordable, and effective menstrual products is a critical reproductive health priority.

The plastic materials volatile organic compounds (VOCs), phthalates are absorbed through the skin with direct contact around the external genitalia were possible to causing PCOS and menstrual irregularities [4&5]. Therefore, ensuring access to safe, affordable, and effective menstrual products is a critical reproductive health priority.

Despite improvements in menstrual product availability, most commercially available disposable sanitary pads contain high amounts of non-biodegradable plastics and synthetic superabsorbent polymers. These materials contribute substantially to environmental pollution, as they require several hundred years to degrade and generate significant solid waste burdens [6]. The environmental impact of menstrual waste has raised growing concerns regarding sustainability and the urgent need for biodegradable alternatives aligned with circular bioeconomy principles [7]. Sustainable innovation in menstrual hygiene products must therefore address both health safety and environmental responsibility.

Sugarcane bagasse, the fibrous residue remaining after juice extraction from *Saccharum officinarum*, represents an abundant and renewable agro-industrial by-product [8]. Globally produced in large quantities by the sugar industry, bagasse is primarily composed of cellulose (40–50%), hemicellulose, and lignin, making it a promising biodegradable biomaterial[8&9]. Cellulose fibers derived from bagasse exhibit excellent absorbency, biodegradability, biocompatibility, and mechanical strength, rendering them suitable for hygienic and biomedical applications [10]. Previous studies have demonstrated the feasibility of converting bagasse-derived cellulose into hydrogels and superabsorbent biomaterials for environmentally friendly applications [11&12].

Valorization of sugarcane bagasse into menstrual hygiene products offers multiple advantages, including sustainable waste management, reduction of plastic dependency, cost-effective utilization of agricultural residues, and promotion of circular bioeconomy strategies. Such approaches align with global sustainability frameworks, including the Sustainable Development Goals [13], by integrating environmental protection with improvements in women's health and well-being.

In this context, the present study focuses on the development of an eco-friendly sanitary pad utilizing

sugarcane bagasse as the primary absorbent material. The study aims to prepare, evaluate, and analyze the performance of the developed pad in terms of absorption capacity, fluid retention efficiency, comfort, hygiene, and user acceptability. By integrating agricultural waste valorization with menstrual health innovation, this research proposes a sustainable, biodegradable, and health-conscious alternative to conventional disposable sanitary pads.

## II. MATERIALS AND METHODS

### 2.1 Materials

Sugarcane bagasse derived from *Saccharum officinarum* was collected as an agro-industrial by-product from local juice vendors. Orthopedic-grade absorbent cotton and biodegradable muslin cloth were procured from certified medical suppliers. Analytical-grade hydrogen peroxide ( $H_2O_2$ ) and dilute sulfuric acid ( $H_2SO_4$ ) were used for chemical pretreatment of lignocellulosic fibers, following established cellulose purification protocols [16&9]. We slightly modified the protocol of Chang et al., 2010 for using gelatin (food/pharmaceutical grade) is a natural biodegradable binder in sheet formation. Distilled water was used throughout the experimental procedures.

### 2.2 Preparation of Bagasse-Based Absorbent Material

#### 2.2.1 Collection of Sugarcane Fibers

Fresh sugarcane bagasse fibers were collected immediately after juice extraction to minimize microbial contamination and biochemical degradation. The material was transported to the laboratory in sterile polyethylene bags for further processing. Figure 1 illustrates the collection of bagasse from the source.

#### 2.2.1 Cleaning and Drying

The collected bagasse fibers were washed thoroughly with distilled water to remove adhering sugars and debris. Removal of soluble sugars is essential to reduce microbial proliferation during storage and processing [10]. The fibers were sun-dried for 48–72 hours and further oven-dried at 60°C to reduce moisture content, which is critical for preventing microbial growth and enhancing material stability [12]. Figure 2 demonstrates the preparation of

sundried and dust particles removed sugar cane fibers to reduce microbial growth.



Figure 1



Figure 2

Figure 1: Depicts the collection of sugarcane bagasse from the source and its shade-drying process before further experimental use.

Figure 2 illustrates the preparation of sugarcane fibers through sun-drying followed by the removal of dust particles to reduce potential microbial growth.

### 2.2.2 Preparation and Chemical Treatment of Bagasse Powder

The dried fibers were mechanically chopped and ground into fine powder. The powdered bagasse was subjected to chemical pretreatment to enhance cellulose purity and absorbency (Figure 3).

Bleaching was performed using dilute hydrogen peroxide to remove residual pigments and improve fiber whiteness and hygiene [15]. Hydrogen peroxide is widely used in lignocellulosic fiber processing due to its effectiveness and relatively low environmental impact[14].

Subsequently, dilute sulfuric acid treatment was applied to partially remove lignin and hemicellulose

components, exposing cellulose microfibrils and enhancing hydrophilicity and absorption capacity [10]. Acid hydrolysis of lignocellulosic biomass has been shown to improve fiber porosity and swelling properties, which are essential for absorbent materials (Spagnol et al., 2012).

Following chemical treatment, the material was repeatedly washed with distilled water until neutral pH was achieved to eliminate residual chemicals. The purified bagasse powder was dried at 50–60°C and stored in sterile conditions until further use.



Figure 3

Figure 3. Demonstrates the Preparation and chemical treatment process of sugarcane bagasse powder.

### 2.3 Pulping and Sheet Formation

The chemically treated bagasse powder was dispersed in distilled water to form a uniform slurry. Gelatin was dissolved separately in warm distilled water and incorporated as a biodegradable binding agent to enhance structural cohesion and mechanical stability of the absorbent sheet[11].

The mixture was heated at 70–80°C with continuous stirring to ensure homogenization. The pulp was then evenly spread onto a greased stainless-steel plate and air-dried under controlled laboratory conditions to form uniform sheets. Cellulose-based sheet formation techniques have been widely reported for absorbent biomaterial fabrication[12].

The dried sheets served as the primary absorbent core of the biodegradable sanitary pad.



Figure 4

Figure 4. Preparation of the absorbent sheet: bagasse powder mixed with gelatin (natural binder) is boiled in water, spread onto a plate, and dried to form uniform sheets. This layer serves as the main absorbent component.

#### 2.4 Assembly of The Biodegradable Sanitary Pad

The sanitary pad was fabricated using a multilayer structure commonly employed in commercial absorbent hygiene products [14].

##### 2.4.1 Top Layer

A biodegradable and skin-friendly muslin cloth was used as the top sheet to ensure breathability, softness, and reduced skin irritation during use.

##### 2.4.2 Middle Absorbent Layer

The prepared bagasse sheet was placed as the central absorbent core. Orthopedic-grade absorbent cotton layers were positioned on both sides to enhance absorption capacity and fluid retention efficiency, consistent with multilayer absorbent product design principles [12].

##### 2.4.3 Bottom Layer

A biodegradable wax-coated sheet was used as the bottom layer to provide leak resistance while maintaining environmental sustainability.

All layers were aligned, compressed, and cut into standardized pad dimensions using sterile tools. The final product was individually packaged in sterile covers for further evaluation (figure 5).

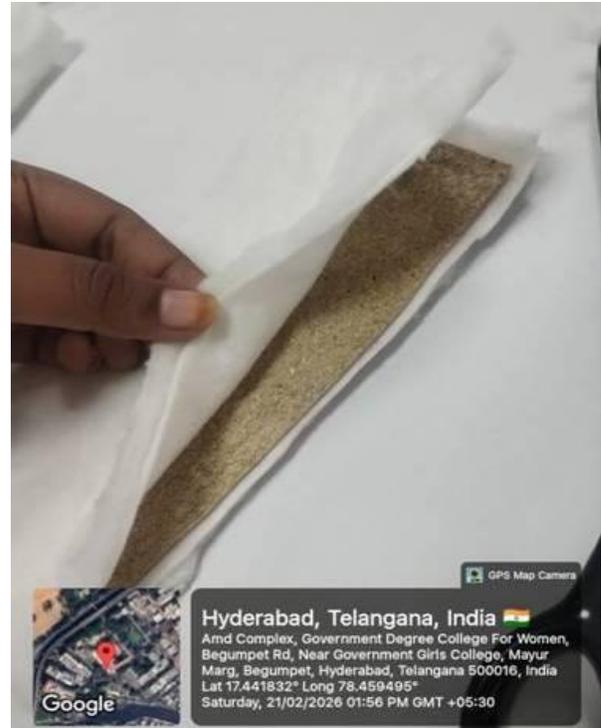


Figure 5. Preparation of the absorbent sheet: bagasse powder mixed with gelatin (natural binder) is boiled in water, spread onto a plate, and dried to form uniform sheets. This layer serves as the main absorbent component.

### III. RESULTS AND DISCUSSION

#### 3.1 Absorption Capacity

The absorption performance of the developed bagasse-based sanitary pad was evaluated at different fabrication stages. The chemically treated bagasse sheet alone exhibited an absorption capacity of 30 mL, indicating the intrinsic hydrophilic nature of cellulose-rich fibers. Cellulose is known for its high water affinity due to abundant hydroxyl groups that promote hydrogen bonding and swelling [11&12].

When orthopedic-grade absorbent cotton was layered on both sides of the bagasse sheet, the absorption capacity increased to 50 mL, demonstrating the synergistic effect of multilayer structuring in enhancing fluid uptake. Multilayer absorbent systems improve capillary action and fluid distribution efficiency, which is a common principle in commercial hygiene products[17]( Figure 5).



Figure 5

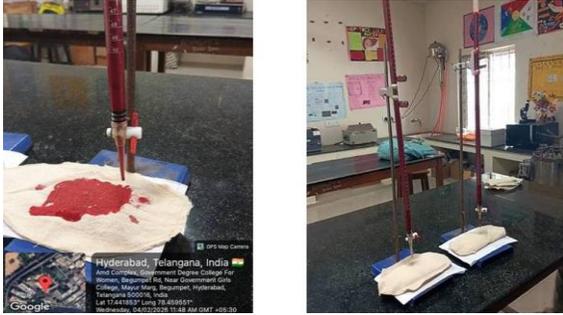


Figure 6

Figure 6. Absorption test performed using goat blood; the absorption capacity was determined as the average of five repeated measurements, the absorption capacity increased to 50 mL.

The fully assembled sanitary pad exhibited a significantly higher absorption capacity of 150 mL when tested with colored water. This enhanced performance may be attributed to improved porosity and fiber swelling following partial lignin removal during acid treatment, which increases cellulose exposure and hydrophilicity [17].

When tested with goat blood, the absorption capacity was 120 mL. The slightly lower absorption compared to water is likely due to the higher viscosity and cellular composition of blood, which can reduce capillary penetration and fluid diffusion rates [18]. Testing with biologically relevant fluids provides a more realistic assessment of menstrual product performance (fig:7).



Figure 7. Absorption test performed using goat blood; the absorption capacity was determined as the average of five repeated measurements, the absorption capacity increased to 50 mL.

These findings suggest that sugarcane bagasse-derived cellulose can function as an effective biodegradable absorbent core material comparable to

other natural fiber-based absorbents reported in sustainable hygiene research.

### 3.2 Leakage Test

Leakage performance was assessed by continuous application of goat blood until breakthrough occurred. The multilayer structure effectively retained fluid without significant lateral leakage up to its absorption threshold. Proper fluid retention within cellulose matrices is associated with fiber swelling capacity and pore structure [18].

The biodegradable wax-coated bottom sheet further prevented downward fluid transmission, consistent with layered absorbent product design principles described in hygiene engineering studies [19]. Adequate leakage protection is essential in menstrual hygiene management to ensure user comfort and prevent staining-related psychosocial stress [1](Figure 8)



Figure 8. Leakage test performed by allowing goat blood to flow through the pad until leakage occurred, to determine its holding capacity.

### 3.3 Comfort Assessment

Comfort evaluation indicated satisfactory softness and breathability. The incorporation of orthopedic cotton enhanced cushioning properties, while the muslin cloth top layer improved air permeability. Breathable natural fibers are known to reduce moisture accumulation and lower the risk of irritation and microbial growth [2].

No major complaints of itching or skin irritation were reported by participants. Dermatological safety is

critical in menstrual products, as prolonged moisture retention and occlusion can increase susceptibility to irritation or infection [3]. The absence of adverse reactions suggests acceptable biocompatibility, although controlled dermatological testing would provide further validation.

### 3.4 Durability Test

Mechanical durability was evaluated by applying a static load of up to 50 kg on a used sanitary pad to simulate sitting and body pressure conditions. The pad maintained structural integrity without rupture or significant leakage.

Mechanical stability in absorbent hygiene products depends on inter-fiber bonding and binder efficiency [20]. The use of gelatin as a natural binder likely contributed to improved structural cohesion of the bagasse sheet. Adequate durability ensures reliability during daily activities and enhances user confidence (Figure 9).



Figure 9

Figure 9. Durability test conducted by applying a load of up to 50 kg on a used sanitary pad to evaluate its structural stability.

## IV. BIODEGRADABILITY ASSESSMENT

Soil burial testing demonstrated visible fungal colonization and earthworm activity within one week, indicating initiation of microbial degradation. Lignocellulosic materials such as bagasse are naturally biodegradable due to susceptibility to fungal cellulases and lignin-degrading enzymes [21]. Compared to conventional plastic-based sanitary pads, which may persist for hundreds of years in landfills [6], cellulose-based materials, degrade significantly faster under composting conditions. The

observed decomposition confirms environmental compatibility and supports circular bioeconomy strategies [7]. Laboratory composting showed slower degradation compared to natural soil, likely due to reduced microbial diversity and environmental variability. Nonetheless, consistent fungal growth confirmed biodegradability. (Figure 10& 11).



FIGURE 10

Figure 10. Soil burial test demonstrating visible fungal colonization and earthworm activity within one week, indicating the onset of microbial degradation.

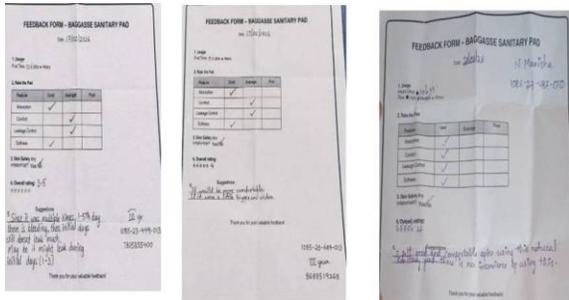


Figure 11

Figure 11. Decomposition rate of the prepared material after 1 and 2 weeks of soil burial.

V. USER PANEL ASSESSMENT – DISCUSSION

User feedback indicated satisfactory absorption performance, good comfort, absence of major skin irritation, and positive acceptance of the eco-friendly nature of the product (Figure 14). Consumer perception studies in menstrual hygiene research suggest that environmental sustainability is increasingly influencing product preference [1]. The positive user response supports the practical feasibility of integrating agro-waste valorization with menstrual health innovation. However, large-scale clinical studies and standardized absorbency testing are recommended for commercialization.



Distribution of User Satisfaction Ratings (n=20 Samples)

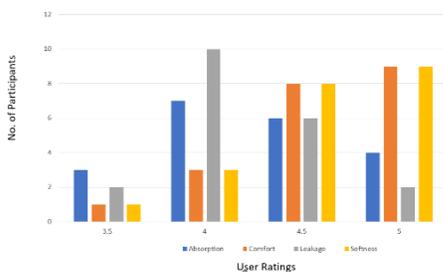


Figure 12

Figure 12. User feedback analysis of the developed sanitary pad.

VI. CONCLUSION

This study demonstrates the potential of sugarcane bagasse fibers as a sustainable, biodegradable, and cost-effective alternative to conventional synthetic absorbent materials used in sanitary napkins. The physicochemical characterization confirmed that processed bagasse fibers possess high cellulose content, adequate porosity, and favorable swelling capacity, all of which are critical for effective menstrual fluid absorption. The developed material exhibited satisfactory absorbency performance, fluid

retention capacity, and structural integrity, indicating its suitability for hygienic applications.

The findings further highlight the environmental advantages of utilizing agricultural waste biomass. Unlike petroleum-based superabsorbent polymers that contribute to long-term plastic pollution, sugarcane bagasse is renewable, biodegradable, and widely available in sugar-producing regions. Its valorization not only reduces agro-industrial waste accumulation but also supports circular bioeconomy principles and sustainable material development.

From a public health and socio-economic perspective, the development of biodegradable sanitary products from locally available natural fibers offers significant implications for menstrual hygiene management, particularly in low-resource and rural settings. The affordability and accessibility of such materials may help reduce dependency on imported synthetic products while minimizing environmental burden associated with menstrual waste disposal.

Overall, the results confirm that sugarcane bagasse fibers can be effectively processed into an absorbent material with promising functional properties for sanitary applications. Future research should focus on large-scale fabrication, product optimization, antimicrobial enhancement, long-term safety assessment, and field-based user acceptability studies to further validate its commercial feasibility and public health impact.

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Conflict of Interest: The authors declare that there is no conflict of interest and that the study was conducted without any external funding.

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