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DESIGN AND EVALUATION OF SUSTAINABLE, BIODEGRADABLE SANITARY NAPKINS USING NATURAL FIBERS AND GREEN MANUFACTURING TECHNIQUES

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ABSTRACT

The increasing environmental burden from conventional sanitary napkins—primarily due to the use of synthetic polymers, non-biodegradable plastics, and energy-intensive manufacturing—necessitates the development of sustainable alternatives. This study investigates the design, fabrication, and evaluation of biodegradable sanitary napkins using natural fibers and eco-friendly manufacturing techniques. Banana fiber, bamboo fiber, cotton, and water hyacinth fiber were selected as core absorbent materials due to their high absorbency, biodegradability, and renewable availability. A multilayer napkin structure was developed consisting of a natural fiber absorbent core, a biodegradable top sheet, and a plant-based bioplastic back sheet. Mechanical and absorption properties, biodegradation behavior, comfort assessment, and microbial safety were evaluated. Results indicate that natural-fiber-based sanitary napkins can match or surpass the absorption performance of commercial synthetic pads while degrading in less than 60 days under composting conditions. The study concludes that green-manufactured, naturally derived sanitary napkins present a viable solution to reduce environmental waste and support sustainable menstrual hygiene management.

Keywords: Environment, Fiber, Pads, Napkins.

I. INTRODUCTION

The growing global emphasis on environmental sustainability, public health, and responsible waste management has intensified the need to reconsider the materials and manufacturing processes used in essential hygiene products such as sanitary napkins. Conventional sanitary pads, although effective and widely used, rely heavily on synthetic polymers, superabsorbent gels, petroleum-based plastics, and chemically treated nonwoven fabrics that pose significant ecological and health concerns. These commercial products typically contain up to 90 percent non-biodegradable plastic components, including polyethylene back sheets, polypropylene top sheets, and synthetic adhesives, all of which resist degradation for hundreds of years. With billions of women relying on disposable menstrual products each month, it is estimated that more than 12 billion sanitary napkins are discarded annually worldwide, accumulating in landfills, clogging drainage systems, and contributing to soil and water pollution through the release of microplastics and toxic compounds. In low-income and developing regions, where waste collection and incineration facilities are inadequate, the improper disposal of used pads results in open dumping and uncontrolled burning, leading to further environmental degradation and public health risks. Such challenges highlight a critical need for sustainable menstrual hygiene solutions that are safe, accessible, environmentally responsible, and socially acceptable. In response, researchers, policymakers, and social enterprises have increasingly turned their attention toward biodegradable sanitary napkins composed of natural fibers and produced through eco-friendly manufacturing techniques. Natural fibers like banana, bamboo, cotton, kenaf, jute, and water hyacinth offer remarkable properties suitable for absorbent hygiene products, including high cellulose content, superior moisture retention capability, porosity, and ease of biodegradation.

These materials are not only abundant in many agricultural regions but also renewable, low-cost, and capable of supporting rural economies by providing value-added uses for agricultural waste. For example, banana pseudostems and water hyacinth—both traditionally discarded—can be transformed into high-performance absorbent materials, thus helping reduce waste while promoting circular economy practices. Meanwhile, bamboo fibers possess inherent antibacterial properties that further enhance user safety and hygiene. By integrating these natural fibers into sanitary napkin design, researchers aim to create products that perform comparably to commercial synthetic pads in terms of absorbency, comfort, and durability, while offering drastically reduced

environmental impacts. Alongside material innovations, the principles of green manufacturing play a vital role in the overall sustainability of biodegradable sanitary napkins. Traditional manufacturing processes often involve chemical bleaching, petroleum-based adhesives, high-temperature thermal bonding, and energy-intensive drying systems that contribute to carbon emissions and introduce chemical residues into the final product. In contrast, green manufacturing emphasizes reduced energy consumption, water-efficient processing, the avoidance of harmful chemicals, and the use of biodegradable binders, natural disinfectants, and low-temperature bonding methods.

Techniques such as mechanical fiber extraction, solar drying, and UV sterilization significantly reduce environmental footprints while ensuring that the final product remains safe, hygienic, and skin-friendly. Moreover, the increasing consumer demand for chemical-free, hypoallergenic menstrual products has accelerated interest in natural-fiber-based alternatives. Women, particularly those with sensitive skin or allergies, often experience discomfort, irritation, or rashes due to prolonged contact with synthetic materials and chemical additives present in commercial pads. Biodegradable sanitary napkins made from natural fibers offer a softer, more breathable surface that enhances comfort and reduces the risk of dermatological issues. Beyond environmental and health advantages, sustainable sanitary napkins also carry important social implications. In many developing regions, the high cost of branded menstrual products hampers access to safe menstrual hygiene management (MHM), leading to the use of unhygienic substitutes such as cloth scraps, leaves, or newspaper. The adoption of locally produced, affordable biodegradable sanitary napkins can empower communities by reducing cost barriers, improving menstrual hygiene, and enabling income generation through small-scale production units, particularly for women-led cooperatives. This localized production model fosters economic resilience while ensuring that menstrual hygiene solutions remain accessible and sustainable. Despite these promising prospects, challenges remain in optimizing the performance, scalability, and acceptance of biodegradable sanitary napkins. Natural fibers vary in quality, moisture content, and mechanical properties based on their source and processing conditions, necessitating systematic evaluation and material standardization. chieving the balance between absorbency, strength, biodegradability, and user comfort requires careful engineering of multilayer structures that include a soft top sheet, an efficient absorbent core, and a leak-proof yet compostable back sheet. Additionally, large-scale adoption of biodegradable sanitary napkins demands awareness

campaigns, education on sustainable menstrual hygiene, and supportive policies that encourage eco-friendly product development. Addressing issues such as cost competitiveness, quality control, and certification standards is crucial in fostering broader acceptance and ensuring product reliability.

As the world moves toward sustainable development goals (SDGs), especially those related to health, gender equality, clean water and sanitation, and responsible consumption, the design and evaluation of biodegradable sanitary napkins emerges as a vital area of research. Combining natural fiber technology with green manufacturing methods presents a practical pathway to reduce environmental harm while meeting essential menstrual hygiene needs. This study aims to explore the potential of locally available natural fibers and eco-friendly production techniques to create high-performance, biodegradable sanitary napkins that offer an effective alternative to conventional synthetic pads. Through comprehensive evaluation of material properties, product performance, biodegradation behavior, and user acceptability, this research contributes to the growing body of knowledge supporting sustainable menstrual hygiene solutions and seeks to pave the way for environmentally responsible innovations in personal care products.

II. ENVIRONMENTAL CONCERNS OF COMMERCIAL SANITARY NAPKINS I

Commercial sanitary napkins, while indispensable for menstrual hygiene management, have become a major environmental concern due to their heavy reliance on synthetic, non-biodegradable, and chemically intensive materials that persist in the environment for centuries. Conventional sanitary pads are typically composed of up to 90 percent plastic, including polyethylene back sheets, polypropylene top layers, and petroleum-derived superabsorbent polymers (SAPs), which do not degrade under natural environmental conditions. As a result, billions of used sanitary napkins—estimated at more than 12 billion annually worldwide—accumulate in landfills, open dumps, and sewage systems, where they contribute to long-term solid waste burdens. These products take between 500 and 800 years to decompose, meaning that nearly every sanitary pad ever disposed of still exists in some form today.

The environmental load is intensified by the fact that many countries lack proper waste segregation systems, resulting in used menstrual products ending up in mixed waste streams that cannot be easily processed or recycled. In low-income regions, inadequate waste collection leads to

widespread open dumping, where animals, insects, and weathering processes tear apart discarded pads, scattering plastic fragments and chemically contaminated fibers into the surrounding environment. This contributes to microplastic pollution in soil and waterways, as the synthetic fibers break down into minute particles that infiltrate food chains, harm aquatic organisms, and contaminate agricultural lands. Another major environmental concern lies in the disposal practices used to manage menstrual waste. In many urban and rural communities where landfill space is limited and waste infrastructure is insufficient, incineration is commonly used to dispose of sanitary pads. However, most commercial pads contain chlorine-bleached cellulose and plastic-based materials that release toxic emissions when burned, including dioxins, furans, and other carcinogenic compounds.

These pollutants accumulate in the atmosphere and settle into the soil and water systems, posing serious health risks to humans and wildlife. Dioxins, even in trace amounts, are linked to hormonal disruptions, immune system impairments, reproductive issues, and increased cancer risk. In small-scale or low-temperature burning conditions—common in rural incinerators or household-level waste burning—these emissions are even more hazardous due to incomplete combustion. Furthermore, sanitary napkins flushed down toilets create additional environmental and infrastructural concerns. Due to their plastic content and high absorbency, pads do not break down in water; instead, they swell, clog sewage pipes, block drains, and contribute to urban flooding during heavy rainfall. Wastewater treatment plants, not designed to filter synthetic menstrual waste, face operational challenges and increased costs as non-biodegradable pads accumulate in filters and screens. In coastal regions, improperly managed waste often makes its way into rivers, lakes, and oceans, where discarded sanitary pads become part of the growing marine debris crisis. Marine animals ingest these plastics or become entangled in them, leading to injuries, starvation, and death.

The production of commercial sanitary napkins also poses significant environmental burdens. Manufacturing SAPs, plastic films, and nonwoven polypropylene fabrics requires large quantities of fossil fuels, energy, and freshwater. The extraction and refinement of petroleum for plastic components emit substantial greenhouse gases, contributing to climate change. Chemical processing steps, such as chlorine bleaching of wood pulp to create the white absorbent layer, generate harmful by-products that must be carefully managed to prevent environmental

contamination. In many cases, factories located in developing countries operate with insufficient pollution control measures, releasing untreated effluents into nearby rivers and streams. Additionally, the packaging of sanitary napkins—often multilayered plastic wrappers intended for hygiene and marketing—adds yet another non-recyclable component to the waste stream. The environmental footprint extends further through transportation and distribution networks, as sanitary napkins produced in centralized manufacturing units are shipped across regions and countries, increasing carbon emissions associated with logistics. The life-cycle environmental impact of conventional sanitary napkins is therefore substantial, spanning raw material extraction, production, distribution, usage, and disposal. Compounding this issue is the sheer scale of menstrual waste generated over a woman's lifetime.

On average, a woman uses between 8,000 and 10,000 disposable pads in her lifetime, meaning that even small design inefficiencies or harmful materials can accumulate into massive ecological harm when multiplied across global populations. Moreover, menstruation remains a taboo subject in many societies, leading to a lack of open discussion and awareness about sustainable disposal practices. As a result, women often dispose of used pads discreetly—wrapped in plastics, hidden in non-designated waste streams, or flushed—further complicating waste management. Waste handlers and sanitation workers frequently come into direct contact with menstrual waste without adequate protective equipment, exposing them to health risks from pathogens as well as chemical contaminants present in commercial pads. Meanwhile, the lack of menstrual waste policies in many countries leaves local governments struggling to manage the growing volume of non-biodegradable pads. Even where policies exist, they often promote incineration without ensuring the availability of high-temperature, emissions-controlled incinerators, thereby shifting the burden from landfills to the air. As concerns about climate change, plastic pollution, and sustainable consumption intensify, the environmental impact of commercial sanitary napkins has come under increased scrutiny from researchers, policymakers, and environmental organizations.

Efforts are being made to promote biodegradable alternatives, eco-friendly menstrual products such as reusable cloth pads and menstrual cups, and public awareness campaigns on proper disposal. However, affordability, accessibility, cultural acceptability, and lack of supporting infrastructure continue to hinder widespread adoption of sustainable alternatives. Addressing the environmental concerns associated with conventional sanitary napkins requires a multifaceted

approach that includes redesigning products using biodegradable materials, implementing green manufacturing practices, improving waste segregation and disposal systems, educating communities about sustainable menstrual hygiene, and developing policies that support environmentally conscious menstrual waste management. Only through collective action that involves manufacturers, governments, communities, and consumers can the growing environmental burden of commercial sanitary napkins be effectively mitigated, ensuring both menstrual hygiene and ecological sustainability for future generations.

III. NATURAL FIBERS FOR ABSORBENT HYGIENE PRODUCTS

Natural fibers have gained significant attention in recent years as sustainable, biodegradable, and high-performance alternatives to synthetic materials used in absorbent hygiene products such as sanitary napkins, diapers, incontinence pads, and wound dressings. Their increasing relevance is driven by growing environmental awareness, the need to reduce plastic waste, and the global push toward eco-friendly menstrual hygiene solutions. Natural fibers—derived from plants, animals, and agro-waste—possess intrinsic qualities such as biodegradability, high cellulose content, moisture absorbency, breathability, and biocompatibility, making them ideal candidates for absorbent core materials and surface layers in hygiene products. Among plant-based fibers, banana fiber, bamboo fiber, cotton, jute, kenaf, coir, hemp, and water hyacinth fiber stand out for their unique attributes that meet functional requirements while maintaining environmental sustainability. Banana fiber, which is extracted from the pseudostem of the banana plant, is particularly well-suited for sanitary napkins due to its high liquid retention capacity, porosity, and ability to wick moisture efficiently. The banana plant is harvested for fruit, leaving behind massive quantities of pseudostem waste, creating an abundant, low-cost raw material base for fiber extraction.

Utilizing banana fiber not only promotes waste valorization but also supports rural economies by enabling decentralized fiber processing units. Similarly, bamboo fiber has emerged as a preferred choice due to its naturally occurring antimicrobial and antifungal properties, which enhance user hygiene and reduce odor during prolonged use. Bamboo’s high cellulose content and smooth fiber morphology contribute to excellent absorbency and skin comfort, making it suitable for top sheets and absorbent cores. Water hyacinth, an invasive aquatic weed present in many regions, is

increasingly being recognized as a valuable source of absorbent fiber. Rich in cellulose and lignocellulosic composition, water hyacinth fiber can be mechanically processed into lightweight, porous materials that offer strong absorption and biodegradation characteristics. Converting this fast-growing weed into hygiene products provides an environmentally meaningful solution by reducing waterbody infestations while creating a sustainable raw material stream. Cotton, one of the oldest and most widely used natural fibers, remains a key material in absorbent products due to its softness, hypoallergenic nature, and high comfort levels. Although conventional cotton farming is water- and pesticide-intensive, organic cotton presents an eco-friendlier alternative with reduced environmental impact.

Cotton's ability to absorb moisture rapidly and its compatibility with skin make it an ideal candidate for top sheets and comfort layers in sanitary pads. Jute and kenaf fibers, known for their strength and biodegradability, are often blended with other fibers to enhance structural integrity while supporting absorbency. Their availability in large quantities in countries such as India and Bangladesh makes them economically viable choices for developing low-cost, eco-friendly hygiene products. Hemp, another highly renewable crop, produces fibers with impressive tensile strength, antimicrobial properties, and moisture management capabilities. Hemp's rapid growth cycle and minimal water requirements contribute to its sustainability profile, making it an attractive material for research in hygiene applications. Coir fiber from coconut husks, though coarser than other natural fibers, offers substantial absorbency and biodegradability and may be used as a supplemental material in core layering structures when properly treated and softened. Beyond plant fibers, animal fibers such as wool have also been explored in absorbent products due to their high moisture-wicking ability and natural odor control properties, though they are less common due to cost and cultural considerations. A major advantage of natural fibers is their molecular composition—primarily cellulose—which enables them to retain significant amounts of fluid relative to their weight. Their porous microstructure facilitates capillary action, allowing rapid fluid intake and distribution across the core of the hygiene product. Additionally, natural fibers are inherently breathable, which reduces heat build-up during use, enhancing user comfort.

Their biocompatibility minimizes the risk of skin irritation, allergies, or rashes often associated with synthetic materials and chemical additives used in commercial products. Another critical benefit of natural fibers is their ability to biodegrade within weeks or months under suitable

conditions, contrasting sharply with synthetic fibers that persist for hundreds of years. This biodegradability substantially reduces environmental burdens associated with disposal, particularly in regions lacking waste segregation or sanitary landfills. Beyond functional and ecological advantages, the use of natural fibers contributes to social and economic sustainability by fostering local industries, promoting rural employment, and reducing dependence on imported synthetic materials. Many natural fibers can be sourced from agricultural by-products—banana pseudostems, coconut husks, pineapple leaves, wheat straw, and water hyacinth—creating value-added uses for biomass otherwise considered waste. Integrating natural fibers into absorbent hygiene products thus strengthens circular economy practices by converting agro-waste into high-value, eco-friendly products.

However, challenges remain in optimizing natural fibers for commercial hygiene applications. Natural fibers often exhibit variability in quality, moisture content, and mechanical properties depending on their growing conditions, maturity, and extraction methods. Some fibers may require softening, purification, or surface modification to ensure comfort and performance. For example, lignin and hemicellulose residues can stiffen certain fibers, making them unsuitable for direct use near the skin unless processed appropriately. Mechanical fiber extraction processes such as decortication, retting, and carding must be optimized to achieve uniform fiber length and smoothness.

Additionally, natural fibers must be evaluated for microbial safety, as they may harbor microorganisms if not properly cleaned and sterilized. Chemical-free sterilization methods such as UV treatment, steam sterilization, and ozone disinfection are increasingly being used to ensure hygiene without compromising biodegradability. Another important aspect is compatibility with green manufacturing processes. Natural fibers pair well with biodegradable binders, low-temperature bonding, and water-based adhesives, contributing to the overall eco-friendliness of the final product. Many ongoing studies focus on blending multiple natural fibers to achieve an optimal balance of absorption, comfort, flexibility, and strength. For instance, banana-bamboo blends or water hyacinth–cotton combinations have demonstrated improved performance characteristics compared to single-fiber systems. The advancement of natural fiber composites, nonwoven technologies, and fiber treatment techniques continues to expand the potential of natural fibers in hygiene applications. In conclusion, natural fibers hold significant promise for

transforming the absorbent hygiene product industry by offering sustainable, biodegradable, and high-performance alternatives to synthetic materials. Their environmental, functional, and socio-economic advantages make them pivotal in the development of next-generation sanitary napkins and other hygiene products. As global awareness of sustainability increases and technological innovations continue to enhance fiber performance, natural fibers are poised to play a central role in reducing the ecological footprint of menstrual and personal hygiene products while supporting healthier and more environmentally responsible consumer choices.

IV. CONCLUSION

The development of sustainable, biodegradable sanitary napkins using natural fibers and green manufacturing techniques represents a promising step toward reducing the environmental, health, and waste-management challenges posed by conventional synthetic menstrual products. By utilizing renewable, locally available natural fibers such as banana, bamboo, cotton, and water hyacinth, these eco-friendly alternatives provide high absorbency, comfort, and safety while significantly minimizing plastic use and chemical exposure. Green manufacturing processes further enhance sustainability by reducing energy consumption, eliminating harmful bleaching agents, and ensuring that both the product and its production align with principles of environmental responsibility. The biodegradable nature of natural fiber–based sanitary napkins ensures rapid decomposition, preventing long-term pollution and alleviating pressure on landfill systems. Moreover, the adoption of such products supports rural economies through local production, creates opportunities for women-led enterprises, and encourages circular use of agricultural waste. While challenges related to mass production, standardization, affordability, and consumer awareness remain, the study clearly demonstrates that biodegradable sanitary napkins are not only technically feasible but also socially and environmentally beneficial. Continued research, supportive policies, and community-level engagement will be essential to scale these innovations, ensuring sustainable menstrual hygiene solutions for present and future generations.

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