Chapter 32

Transforming Agricultural and Plant-based Byproducts into Compostable Hygiene Materials for a Circular Economy

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Abstract

This study investigates cellulose fibres from agricultural byproducts for use in absorbent materials. Harvest residues such as stalks and leaves were sourced from local farms and processed through mechanical and chemical treatments to extract cellulose fibres. The cellulose fibres were used to produce nonwovens and fluff pulp, which were evaluated through in-house and external absorbency testing. Fluff pulp showed performance significantly greater than kraft wood pulp, while wet-laid nonwovens absorbed 9.5 mL/g of simulated menstrual fluid. Pilot-scale composting tests (ISO 16929:2021) demonstrated that a prototype menstrual pad (A-Pad) made from agricultural byproducts achieved 96.7% ± 3.3% disintegration after 63 days, outperforming bamboo (31.8% ± 7.6%) and cotton-based (46.4% ± 12.2%) pads. Converting agricultural residues into compostable materials provides a sustainable alternative to cotton, bamboo, wood pulp, and synthetics, reducing landfill waste and supporting rural economies, while advancing circular practices in the hygiene industry.

Keywords: *Cellulose fibres, Agricultural and plant-based byproducts, Compostable materials, Absorbent hygiene products, Circular economy*

Introduction

The absorbent hygiene industry faces growing demand for sustainable materials to mitigate the environmental impact of non-degradable waste. Conventional products such as menstrual pads and diapers rely on plastics (polypropylene, polyethylene) and superabsorbent polymers, which can take up to 800 years to degrade in landfills[1]. Alternatives marketed as sustainable often use cotton, bamboo, or wood-based fluff pulp, which, though compostable under specific conditions, are resource-intensive. Cotton requires ~10,000 L of water per kg and accounts for 16% of global insecticide use on only 2.3% of arable land[2]. Bamboo textile processing requires toxic chemicals (e.g., carbon disulfide), increasing its environmental footprint[3]. Wood pulp production drives deforestation and high energy use[4].

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[1]Smitikana Ray et al., "Sanitary Waste and Microplastic Pollution in the Euro-Mediterranean Region: Challenges and Solutions," *Euro-Mediterranean Journal for Environmental Integration* (published July 16, 2025), https://doi.org/10.1007/s41207-025-00879-y.

[2]Zhang Zhenggui et al., "Environmental Impacts of Cotton and Opportunities for Improvement," *Nature Reviews Earth & Environment,* 4 (2023): 703–715, https://doi.org/10.1038/s43017-023-00476-z.

[3]Amjad, Akhtarul Islam, "Bamboo Fibre: A Sustainable Solution for Textile Manufacturing," *Advances in Bamboo Science* 7, (2024) (May): 100088, https://doi.org/10.1016/j.bamboo.2024.100088.

[4]Zhao, Qingjian et al., "Energy Flows and Carbon Footprint in the Forestry-Pulp and Paper Industry," *Forests* 10 no. 9 (2019): 725, https://doi.org/10.3390/f10090725.

Burning agricultural residues produces ~3.5% of global greenhouse gas emissions[5], releasing significant amounts of CO_2, CH_4, and N_2O into the atmosphere, contributing to climate change, with significant portions burned in fields in countries India[6] and the USA[6] exacerbating air pollution and greenhouse gas emissions. This study introduces a circular economy approach, transforming agricultural byproducts such as banana, hemp, and bullrush into compostable absorbent materials for hygiene products. Valorising agricultural waste minimizes landfill use, reduces resource depletion, and supports rural economies, while advancing scalable, high-performance alternatives to conventional materials.

Results and Discussion

Cellulose Fibre Extraction

Agricultural residues were mechanically processed to break down stalks and increase surface area. A subsequent chemical treatment extracted cellulose fibrils from the surrounding hemicelluloses, lignin, and waxes[7]. The material was impregnated with reagents, strained, washed, and dried, yielding 40–60% after combined mechanical and chemical losses.

Fibre Characterisation

After extraction, cellulose fibre yield varied with the type and quality of agricultural material. The fibres differed in length, bulk density, and absorbency, and could be processed into nonwovens for use in disposable hygiene products such as menstrual pads, incontinence pads, maternity pads, and diapers.

Fluff pulp, a highly absorbent material typically made from softwood kraft, was reproduced from agricultural fibres by defibrillation in a blender, producing a soft, absorbent[8].

Nonwovens were produced using a wet-laid method. Extracted fibres were dispersed in water, filtered through a fine screen to form a mat, and then dried in an oven and at room temperature.

Test samples (250 g/m², 9 × 9 cm) absorbed about 9.5 times their mass in simulated menstrual fluid, as shown in Table **1**. Specifically, a nonwoven with a basis weight of 250 g/m² absorbed 2374 g of fluid per m², equivalent to 2381 mL/m² (given the fluid density of 0.997 g/mL). This performance exceeds cotton-based absorbents (6–8 g/g) and matches the upper range of commercial wood pulp fluff (8–11 g/g), showing that nonwovens from agricultural byproducts can compete with conventional absorbent materials.

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[5]Ritchie, Hannah, "GHG Emissions by Sector," *Our World in Data*, Accessed August, 2025, https://ourworldindata.org/ghg-emissions-by-sector.

[6]Lan, Ruoyu et al., "Air Quality Impacts of Crop Residue Burning in India and Mitigation Alternatives," *Nature Communications* 13 (2022): 6537, https://doi.org/10.1038/s41467-022-34093-z.

[7]Parida, Pramod Kumar et al., "Extraction of Natural Cellulosic Fiber from *Myriostachia wightiana* Stems Using Chemical Retting and Its Characterization for Bio-Composite Applications," *Cellulose* 30 (2023): 8819–8837, https://doi.org/10.1007/s10570-023-05438-8.

[8]Ismaeilimoghadam, Saeed et al., "Manufacturing of Fluff Pulp Using Different Pulp Sources and Bentonite on an Industrial Scale for Absorbent Hygienic Products," *Molecules* 27 no. 15 (2022): 5022 https://doi.org/10.3390/molecules27155022.

Table 1: Absorbency test results of nonwovens made from 100% cellulose fibres.

Sample	Dry Mass (g)	Wet Mass (g)	Absorbed Fluid (g)	Absorbency ($g_{fluid}/g_{textile}$)
1	0.913	9.817	8.904	9.752
2	0.682	7.158	6.476	9.496
3	0.735	7.527	6.792	9.241
Average	–	–	–	9.496

Absorbency Testing of Fluff Pulp

To evaluate fluff pulp absorbency, cylindrical test pieces (3 g, 50 mm diameter) were prepared using a dust cyclone and vacuum to evenly distribute pulp into a 3D-printed mold, as shown in Figure **1**. Each piece was placed on a perforated disk above 900 mL of water, loaded with 500 g for uniform pressure, immersed for 2 min, then drained for further 2 min. Absorbent capacity was calculated as (W_{wet} - W_{dry}) / W_{dry}, where W_{wet} and W_{dry} are the wet and dry weights of the test piece, respectively. This in-house method provided reproducible results with simple equipment.

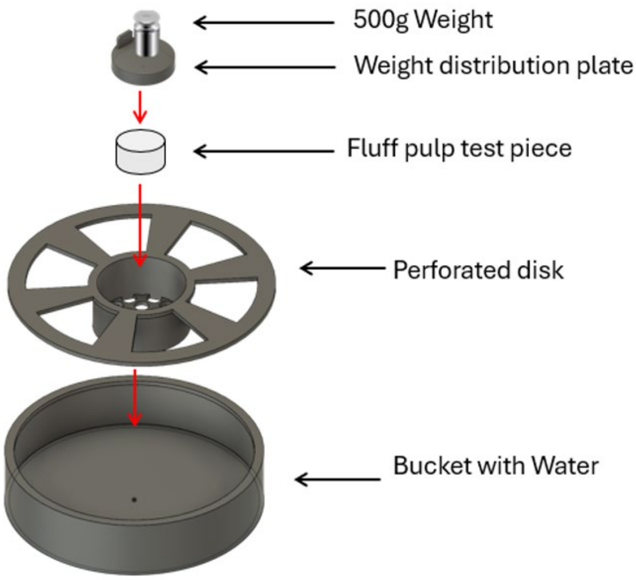

Figure 1: 3D-printed test piece for absorbency testing.

Table **2** compares the absorbency of kraft softwood pulp (control) with fluff pulp from bullrush, banana, and hemp.

Table 2: Average absorbency test results of fluff pulp from bullrush leaf, banana stem, and hemp hurd. Three replicates of each sample type were tested.

	Dry Mass (g)	Wet Mass (g)	Absorbency ($g_{fluid}/g_{textile}$)
Wood pulp (Control)	2.99	33.32	10.16
Bullrush fluff pulp	2.97	48.62	15.37
Banana fluff pulp	2.94	48.31	15.43
Hemp fluff pulp	3.02	55.13	17.25

Disintegration Under Compost Conditions

Composting is the aerobic biodegradation of organic waste into nutrient-rich material[9]. Assessing disintegration at pilot scale is essential, since the compostability of raw cellulose fibres may differ once processed into products. To test this, a prototype pad (A-Pad) made from our cellulose fibres was compared with two commercial products: a bamboo-based pad (B-Pad) and a cotton-based pad (C-Pad), as disclosed on their respective websites.

Test products used in this study:

- **A-Pad**: Composed of a pressed banana fibre layer, a hemp fibre absorbent core, hemp lining, a starch-based plastic wrapper, and a plant-based adhesive.
- **B-Pad**: Composed of a compostable wrapper, a bamboo/cornstarch fibre absorbent layer, a food-grade non-toxic adhesive, and a bioplastic pad lining.
- **C-Pad**: Composed of a bioplastic wrapper, an organic cotton/sustainable wood pulp absorbent layer, and a bioplastic pad lining.

Disintegration followed ISO 16929:2021[10]. The degree of disintegration for each test product was calculated using the equation: ($\frac{mass_{final} - mass_{initial}}{mass_{initial}} \times 100$).

Three compost tumblers were used: one control and two test replicates (Trial A, Trial B), each containing 12 pads (four of each type). Pads were sealed in nylon mesh bags with biowaste (food scraps, yard waste, and unbleached paper) and inoculated with mature compost. Tumblers were turned weekly, with biowaste replenished to sustain volume and temperature. Compost temperature, pH, moisture, and odour were monitored regularly to maintain optimal conditions, with weekly turning for aeration and mixing.

After 63 days, temperature (max 55–57C, avg. 43C), moisture, and pH stayed within optimal ranges. Consistently earthy odours confirmed stable aerobic composting.

The following Table **3** shows a summary of the results from the disintegration testing:

Table 3: Average test product characteristics at the end of the 9-week compost disintegration experiment. Standard deviations are shown in parentheses.

	Average of Initial Mass (g)	**Average of Final Dry Mass (g)**	**Average of Degree Disintegration**
A-Pad	14.02(3.73)	4.60(3.13)	96.7%(3.3%)
B-Pad	7.32(0.06)	4.98(0.53)	31.8%(7.6%)
C-Pad	7.69(0.05)	4.12(0.96)	46.4%(12.2%)

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[9]Genetu, Amare, "Composting Technology for Municipal Solid Waste Management and Production of Organic Fertilizer," *Advances in Environmental Waste Management & Recycling* 7 no. 2 (2024): 1–13.

[10]International Organization for Standardization (ISO), *ISO 16929:2021 Plastics—Determination of the Degree of Disintegration of Plastic Materials under Defined Composting Conditions in a Pilot-Scale Test*, 4th ed. (Geneva: International Organization for Standardization, 2021).

Conclusion

This study demonstrates that agricultural byproducts such as banana stalks, hemp hurds, and bullrush biomass can be transformed into high-performance, compostable absorbent materials for hygiene products. Our fibres outperformed conventional, resource-intensive cotton and bamboo in both absorbency and compostability, with prototype pads achieving nearly complete disintegration under ISO 16929 conditions.

Extracted cellulose fibres were processed into fluff pulp and nonwovens, with fluff pulp absorbency reaching 15.37 g/g (bullrush), 15.33 g/g (banana), and 17.25 g/g (hemp), values much higher than the 10.16 g/g of standard wood pulp. Pilot-scale composting (ISO 16929:2021) showed that a prototype A-Pad, made from banana and hemp fibres, disintegrated by 96.7% ± 3.3% after 63 days, outperforming bamboo-based (31.8% ± 7.6%) and cotton-based (46.4% ± 12.2%) commercial pads, underscoring the materials' disintegration under composting conditions.

While further testing and industrial scale-up are needed, the results show that agricultural residues can rival and surpass established raw materials. By turning overlooked waste streams into valuable fibres, this work reduces landfill pressure, conserves resources, and supports rural economies.

The findings point toward a circular future for the hygiene industry, one where performance and sustainability go hand in hand, and where agricultural byproducts become a cornerstone of low-impact, next-generation materials.

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