Development of sustainable hygiene products from sugarcane bagasse

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Abstract
Commercial sanitary napkins typically consist of three to four distinct layers, each engineered to perform a specific function. Most branded products incorporate a permeable top sheet composed of polypropylene to facilitate fluid transfer, an absorbent core consisting of superabsorbent polymers (SAPs) or cotton fibers for fluid retention, and an impermeable back sheet made of polyethylene to prevent leakage. However, these materials are predominantly synthetic, non-biodegradable, and pose significant environmental challenges due to their persistence in landfills.

This study addresses the environmental implications associated with conventional sanitary products and aims to develop an eco-friendly alternative utilizing agricultural waste. Specifically, sugarcane bagasse (SCB) a fibrous byproduct of the sugar industry—has been processed into a fine cellulosic pulp and evaluated for its suitability as an absorbent core material. A laboratory-scale prototype sanitary napkin was fabricated using a permeable top layer of absorbent cotton gauze, a three-layered core of sugarcane bagasse pulp, and a hydrophobic cotton fabric as the back sheet.

The research focuses on replacing petroleum-based synthetic components with biodegradable and sustainable materials without compromising performance. Preliminary findings indicate that the sugarcane bagasse-based sanitary napkin demonstrates favorable absorbency and fluid retention characteristics while being fully biodegradable, offering a viable solution for reducing environmental impact.

Key words:
Bio degradability, Eco friendly, Sustainability, Sugarcane bagasse, Sanitary napkin,

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1.0 Introduction

In recent years, there has been a growing demand among both consumers and environmental advocates for environmentally sustainable and biodegradable products for daily use [1]. This shift in consumer preference has significantly influenced the commercial market, particularly in the domain of hygiene-related products such as diapers for infants and adults, as well as feminine hygiene products including sanitary napkins [2]. However, the majority of commercially available absorbent hygiene products are composed of synthetic, non-biodegradable materials, raising concerns regarding their environmental sustainability.

Sanitary napkins currently available in the market typically comprise 30–40% non-biodegradable constituents, such as synthetic fibers, polyethylene, polypropylene sheets, and superabsorbent polymers (SAPs) [3,4]. Branded multinational products generally consist of a perforated polypropylene top sheet that remains in contact with the body to maintain dryness, a core composed of SAPs or cellulosic absorbents for fluid retention, and a hydrophobic polyethylene back sheet to prevent leakage [4]. Consequently, the disposal of these products poses a significant challenge to environmental agencies and municipal waste management authorities due to their persistence in landfills [5].

Moreover, the high cost of commercial feminine hygiene products often renders them inaccessible to rural populations. In India, pricing is a critical factor influencing consumer decisions, particularly in economically constrained regions. Studies indicate that a substantial portion of the rural population, especially from lower-middle-income groups, lacks access to hygienic menstrual products, often resorting to unhygienic practices during menstruation [6]. Therefore, to improve menstrual health and hygiene for millions of rural women in India and

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globally, there is an urgent need for low-cost, biodegradable sanitary pads derived from sustainable raw materials.

Similar biodegradability concerns exist for disposable baby and adult diapers, which also incorporate large proportions of synthetic, non-degradable materials [7]. The primary functional requirement of such products is their capacity to absorb and retain bodily fluids. To achieve high absorbency, manufacturers have conventionally employed synthetic polymers, which outperform natural fibers in moisture retention [7]. Despite significant technological advancements in the diaper manufacturing industry, critical challenges remain—particularly in enhancing biodegradability and environmental sustainability. With growing awareness of the environmental burden caused by disposable sanitary products in landfills, manufacturers are now increasingly exploring biodegradable alternatives [8–10].

In this context, the utilization of agricultural waste—such as sugarcane bagasse—for the development of superabsorbent hygiene products represents a promising and sustainable solution. Not only would this innovation improve access for economically disadvantaged populations, but it would also contribute to environmental conservation by reducing plastic waste. Sugarcane, a major cash crop, is extensively cultivated in several countries, with India's Uttar Pradesh, Maharashtra, and Karnataka accounting for nearly 80% of the nation's sugar production [11,12]. During the 2023–24 season, India produced approximately 4,531 lakh metric tons (LMT) of sugarcane, with Maharashtra alone contributing 1,076 LMT.

Sugarcane processing generates various forms of agricultural waste, including dry leaves, tops, press mud, molasses, and notably, sugarcane bagasse (SCB). For every 100 tons of sugarcane processed, roughly 30 tons of bagasse are produced as byproduct. Bagasse is a fibrous material rich in cellulose (approximately 40–50%), along with hemicellulose, lignin, and waxes [13,14]. Due to its high cellulose content, year-round availability, and status as a byproduct, SCB presents an ideal raw material for producing absorbent cores in hygiene products. Importantly, its processing does not require hazardous chemicals, making it an environmentally benign option. The conversion of bagasse into biodegradable sanitary products using green technologies thus represents a significant advancement in sustainable product development.

2.0 Material and methods

2.1 Materials

Sugarcane bagasse procured from a local sugarcane juice vendor in Mumbai. Sodium hydroxide (98%), Hydrogen peroxide (30%) and Sulphuric acid (95%) purchased from Merck India ltd.

2.2 Methods

2.2.1 Synthesis of pulp sheet from sugarcane bagasse

A predetermined quantity of sugarcane bagasse (SCB) was initially subjected to thorough washing with distilled water to eliminate surface waxes and residual sugars. The cleaned bagasse was then oven-dried to a constant weight. To remove lignin and facilitate delignification, the dried SCB underwent an acid pre-treatment using dilute sulfuric acid. Following the acid treatment, the material was rinsed thoroughly with water to remove residual acid and neutralize the pH.

Subsequently, an alkali treatment was applied to the delignified material to remove hemicellulose components and enhance cellulose purity. Sodium hydroxide (NaOH) solutions at varying concentrations (0.5% to 2.0% w/v) were employed in a series of trials conducted at 100°C to determine optimal treatment conditions. The resulting cellulose pulp was washed repeatedly with distilled water until a neutral pH was achieved.

The neutralized pulp was then molded into uniform thin sheet layers and air-dried. Each batch was evaluated based on key parameters including absorbency, softness, and flexibility of the formed pulp sheets. Additionally, the yield of cellulose pulp obtained from each treatment was quantified by measuring the final dry weight, enabling process optimization based on both material performance and processing efficiency.

2.2.2 Analysis of pulp sheet and SCB sanitary napkin

The absorbency of the cellulose pulp sheets and prototypes of sugarcane bagasse (SCB)-based sanitary napkins were assessed following the IS 5405 test method, which is standardized for the evaluation of absorbent materials. Absorbency tests were conducted on both commercial sanitary napkins and the developed prototypes using a blood substitute fluid, prepared in the laboratory. The blood substitute was formulated by dissolving 164 g of salt and 100 mg of red dye in 896 ml of distilled water to simulate the fluid absorption properties.

The vertical wicking behavior of the pulp sheet and napkin prototypes was analyzed in accordance with AATCC 197, a method for measuring the rate of liquid absorption through fabric. Fluid retention capacity, which quantifies the material's ability to retain absorbed fluids, was determined using an in-house test procedure designed to simulate typical use conditions.

Air permeability of the prototypes was evaluated following the IS 11056 standard, which defines the test for determining the resistance of fabrics to airflow. Finally, the environmental performance of the products was assessed based on the Oeko-Tex Standard, which provides guidelines for measuring ecological and safety parameters in textile products.

3. Results and Discussions

3.1 Synthesis of SCB pulp

A sample of 10.0 g of washed and dried sugarcane bagasse was subjected to pre-treatment with a 1.0% sulfuric acid solution, which was boiled for 2 hours. After the pre-treatment, the residue was thoroughly washed with distilled water to remove any residual acid. Following this, the residue was treated with sodium hydroxide (NaOH) solution under continuous stirring for 5–6 hours. Various trials were conducted using NaOH concentrations ranging from 0.25% to 2.0%, with the aim of achieving a soft pulp with optimized fluid retention properties.

A photographic representation of the various stages involved in the synthesis of the pulp sheets from the bagasse is shown in Figure 1A to 1D. The characteristics of the pulp obtained and the corresponding yield of the pulp residue at different NaOH concentrations are summarized in Table 1.

Fig 1A Sugarcane Bagasse

Fig 1B Acid pre treatment of SCB

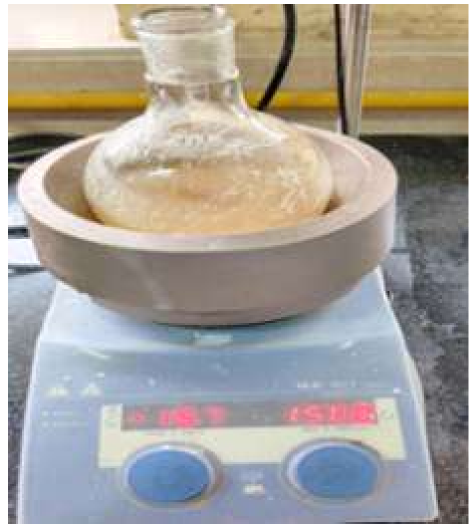

Fig 1C Alkali treatment of SCB

Fig 1D SCB pulp

Fig.1E SCB pulp sheets

Table-1 SCB pulp yield and properties

NaOH Concentration (%) for making pulp sheet	Product	Nature of product	Yield (%)
0.25	Fibre	Thick loose fibre.	90-95
0.5	Mixture of fibre and pulp	Soft sheet	45-47
1.0	Pulp	Soft sheet	40-42
1.5	Pulp	Slightly stiff sheet	35-37
2.0	Pulp	Very stiff sheet	33-35

From Table 1, it is evident that bagasse treated with a 0.25% NaOH solution remained in a fibrous form and could not be molded into a sheet. The yield of fibers in this case was 90–95%, indicating a mixture of hemicelluloses and cellulose fibers. In contrast, bagasse treated with 0.5% and 1.0% NaOH solutions resulted in a pulp form, which could be easily molded into thin sheets. The pulp yield for these treatments was 47% and 42%, respectively. Bagasse treated with 1.5% and 2.0% NaOH solutions also resulted in pulp sheets; however, these sheets were comparatively stiffer. This stiffness is likely due to the formation of a purer pulp, as higher concentrations of alkali likely converted all the fibers into pulp. Additionally, the yield of pulp obtained at 1.5% and 2.0% NaOH concentrations was lower than that from the 0.5% and 1.0% treatments. These findings suggest that the optimal concentration of NaOH required for producing soft pulp sheets with good molding properties is within the range of 0.5–1.0%.

3.2 Water absorbency of SCB pulp sheet

The water absorbency of the obtained pulp was qualitatively assessed using the AATCC 79 (drop test) method. In this procedure, a single drop of water was allowed to fall from the tip of a burette positioned 10 mm above the pulp specimen. The time taken for the water drop to lose its light reflection and transition into a dull, wet spot was recorded. The water absorbency values for each pulp sample, as determined by the drop test, are presented in Table 2.

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Table-2 Absorbency of SB pulp sheet

NaOH concentration (%) for making pulp sheet	Character off pulp	Absorption time (sec)
0.25	No pulp formation. Loose fibres	? 3
0.5	Soft pulp sheet	< 1.0
1.0	Soft pulp sheet	< 1.0
1.5	Slightly stiff pulp sheet	< 1.0
2.0	Very stiff pulp sheet	< 1.0

From Table 2, it is evident that the pulp synthesized using NaOH concentrations ranging from 0.5% to 2.0% demonstrated excellent water absorbency, with absorption times of less than 1.0 second. In contrast, the pulp obtained from the 0.25% NaOH treatment exhibited poor absorbency, with the time to absorb water exceeding 3.0 seconds. This observation suggests that a 0.25% NaOH concentration is insufficient to produce an absorbent pulp.

3.3 Absorption property of SCB pulp sheet as vertical wicking time

The vertical wicking ability of the pulp sheets was measured in accordance with the AATCC 197 test method. This method evaluates the rate at which liquid travels along and through the specimen due to capillary action. The test was conducted by visually observing the rise of the liquid, manually timing, and recording the movement at specified intervals.

Specimens, measuring 165 mm in length and 25 mm in width, were marked at 5 mm intervals from one end of the specimen. The 5 mm line indicated the starting point at which the specimen was to be submerged into the fluid in the beaker. Additional markings at 20 mm, 50 mm, and 100 mm above the 5 mm line represented the heights to be monitored. The specimen was suspended in the beaker, and fluid was added until the liquid level reached the 5 mm line of the specimen, marking the commencement of the test. The stopwatch was started at this point, and the rise of the fluid through the specimen due to capillary action was observed. The time taken for the fluid to reach the 20 mm, 50 mm, and 100 mm marks was recorded. The wicking times for the pulp sheets synthesized using NaOH concentrations of 0.5%, 1.0%, 1.5%, and 2.0% are presented in Table 3.

From Table 3, it can be observed that the pulp synthesized using 0.5% NaOH exhibits a low wicking time, indicating a faster capillary action. This is likely due to the presence of more fibers in the pulp. As the NaOH concentration increases, more pulp is formed, and the fiber content decreases, resulting in a reduction in capillary action and an increase in wicking time. Figure 2 provides a photographic representation of the wicking experiment.

Table-3 Wicking time of bagasse pulp sheet

NaOH concentration (%)for making pulp sheet	Vertical height 20 mm	Vertical height 50 mm	Vertical height 100 mm
	Time (Seconds)	Time (Seconds)	Time (Seconds)
0.5	7	49	277
1.0	6	50	360
1.5	8	64	394
2.0	10	122	638

Table-4 Absorbency of bagasse pulp sheet

NaOH concentration (%) for making pulp sheet	Number of layer	Wt of pulp (g)	Vol. of water (ml)	Observation
0.5%	2	9.4	30	Fully absorbed
1.0%	2	8.4	30	Fully absorbed
1.5%	2	7.5	30	Fully absorbed

From Table 3, it can be observed that the pulp synthesized using 0.5% NaOH exhibits a low wicking time, indicating a faster capillary action. This is likely due to the presence of more fibers in the pulp. As the NaOH concentration increases, more pulp is formed, and the fiber content decreases, resulting in a reduction in capillary action and an increase in wicking time. Figure 2 provides a photographic representation of the wicking experiment.

Figure-2 Photograph of the wicking experiment

3.4 Horizontal absorbency of SCB pulp sheet

The absorption capacity of water in the pulp sheets was determined in accordance with the IS 5405 test method. Two layers of pulp sheets were placed on a transparent glass plate to allow observation of the underside of the sanitary napkin. A volume of 30 ml of colored water was gradually added drop by drop at a rate of 5 ml/min from a burette, positioned 1–2 mm above the sheet, and focused on the center of the specimen. Once the sheet had absorbed the entire 30 ml of colored water, a standard weight of 1.0 kg was placed on the area where the colored water was absorbed and left for 1 minute. After this, the entire length and width of the pulp sheet were examined for uniformity in absorption. The absorption properties are summarized in Table 4. Figure 3 illustrates photographs of the absorbency test procedure.

Table-4 Absorbency of bagasse pulp sheet

Fig.3A SCB sheet before absorption

Fig.3B Absorption process

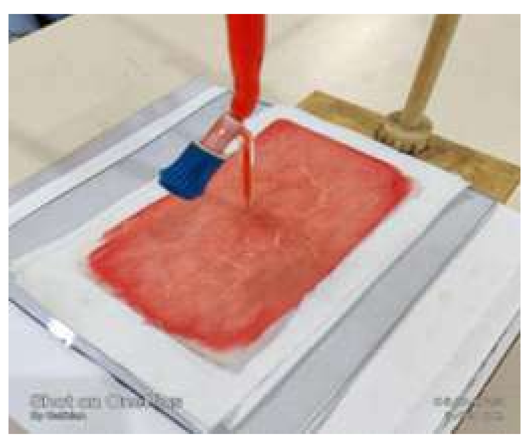

Fig. 3C fully absorbed sheets

Fig. 3D absorbed sheet under a load of 1kg.

From Table 4 it is observed that bagasse pulp sheet synthesized using 0.5, 1.0, 1.5 % NaOH is capable of holding 30 ml of coloured water with a pressure of 1 kg weight.

3.5 Water retention property of bagasse pulp sheet

The water retention capacity of the pulp sheets, defined as the maximum volume of water that can be absorbed per gram of material, was measured in terms of ml/g or g/g. To determine this property, two layers of pulp sheets were weighed and placed on a stand set at a 45° inclined angle. Colored water was then added from a 50 ml burette at a rate of 5 ml/min, positioned at the top of the sheet. Water was allowed to absorb from the top of the sheet, gradually progressing to the bottom until the sheet became saturated. The flow from the burette was halted when the first drop of water began to drip from the sheet. The burette reading was recorded, and the water retention capacity was calculated in terms of g/g. Additionally, the time taken for the sheet to absorb the water was also noted. The water retention capacity of bagasse sheets synthesized with 0.5%, 1.0%, and 1.5% NaOH concentrations is presented in Table 5. A photographic representation of the water retention test is shown in Figure 4.

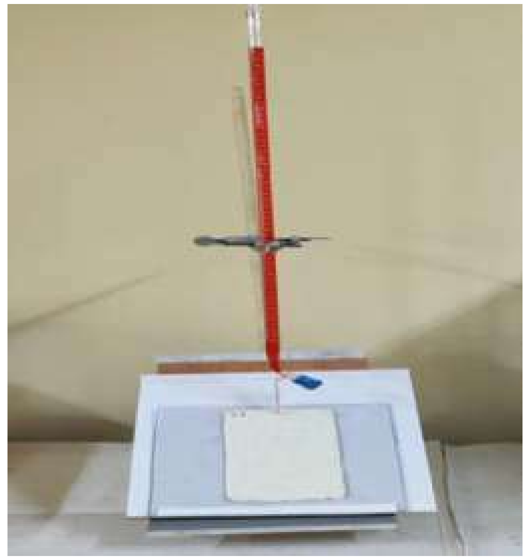

Fig.4 Photograph of water retention capacity test

From Table 5, it is evident that the bagasse pulp synthesized with 0.5%, 1.0%, and 1.5% NaOH concentrations exhibited average water holding capacities of 6.15 ml/g, 7.7 ml/g, and 4.4 ml/g, respectively. This clearly indicates that the pulp synthesized with 1.0% NaOH has higher water holding capacity compared to both the 0.5% and 1.5% NaOH treated samples. Additionally, the absorption time for the pulp synthesized with 1.0% NaOH was the shortest among all the samples.

Based on the trials conducted for synthesizing bagasse pulp using various NaOH concentrations, and considering the performance characteristics of the resulting pulp sheets, it was observed that the pulp synthesized with 1.0% NaOH exhibited superior water absorption and water holding capacity. Furthermore, this pulp was found to be softer and more flexible than the pulp produced with 0.5% and 1.5% NaOH.

Table-5 Water retention capacity of bagasse pulp sheet

NaOH concentration (%) for making pulp sheet	Weight of Bagasse pulp sheet (g)	Absorption time (min)	Volume of water (ml)	Water retention capacity (ml/g)	Average (ml/g)
0.5	3.9290	3.0	25.0	6.3	6.15
0.5	4.7832	5.0	28.9	6.0	
1.0	3.8985	2.5	30.0	7.7	7.7
1.0	3.7428	2.5	29.0	7.7	
1.5	3.4196	3.0	15.6	4.5	4.4
1.5	3.7095	3.2	16	4.3	

Consequently, in the laboratory-scale synthesis, approximately 100 sheets of bagasse pulp, each measuring 30 cm in length, 9 cm in width, and 2 mm in thickness, were produced using 1.0% NaOH. Since the goal of this study was to develop sustainable hygiene products from sugarcane bagasse, significant emphasis was placed on ensuring eco-friendliness and biodegradability, while not compromising on performance or comfort.

Eco-friendliness was assessed by testing various eco-parameters, including plasticizers, chlorophenols, formaldehyde, and bisphenols. Biodegradability was evaluated through soil burial tests. Performance evaluations were conducted with respect to absorption capacity and absorption rate. Additionally, comfort level was gauged through feedback obtained from user trials and user panels.

3.6 SCB sanitary napkin prototype design

Approximately 30 sugarcane bagasse (SCB) sanitary pads were prepared in the laboratory for performance evaluation. The SCB napkins were designed with a multi-layer structure, consisting of one hydrophobic cotton fabric as the outer layer, followed by three middle layers of SCB pulp sheets, and an inner layer of absorbent cotton gauze fabric. These five layers were stitched together along the outer borders after being shaped into the form of a sanitary napkin.
In contrast, most commercially available branded sanitary napkins consist of a polyethylene sheet as the outer layer, with cotton fibers or super absorbent polymer (SAP) forming the middle layer, and a perforated polypropylene sheet in the innermost layer. These three layers are typically thermally bonded.

Figures 5A and 5B depict cross-sectional photographs of a commercial sanitary napkin and an SCB-based sanitary napkin, respectively

A comparative study was conducted to evaluate the performance of SCB sanitary napkins in comparison to five branded commercial sanitary napkins: Whisper, Stayfree, Pro-ease, Sofy, and Paree. Most of the performance tests were carried out in accordance with the IS 5405 specifications for sanitary napkins. Since none of the existing specifications for sanitary napkins cover eco-parameters, these were tested using Gas Chromatography-Mass Spectrometry (GC-MS) (Shimadzu QP 2020 NX) in compliance with Oeko-Tex 100 standards. The air permeability of the napkins was evaluated using an APT/S auto air permeability tester, as per the IS 11056 method. The biodegradability of the napkins was assessed by conducting soil burial tests, following the ISO 11721-1 standard.

3.7 Performance evaluation of SCB sanitary napkin against commercial sanitary napkins.

The ability of SCB sanitary napkins to withstand pressure after fluid absorption was measured in accordance with the IS 5405-2019 test method. As per the procedure, the sanitary napkin was placed on a transparent glass plate to allow observation of the underside. A total of 30 ml of blood substitute fluid was added drop by drop from a burette, at a rate of 5 ml/min, to the center of the napkin from a height of 1-2 mm. After the napkin had absorbed the full volume of fluid, a standard weight of 1.0 kg was applied for 1.0 minute on the portion where the colored fluid had been absorbed. The bottom and sides of the napkin were then observed for any fluid leakage. The test sample passes if no liquid leaks through and fails if leakage occurs. The observations from the pressure tests of the sanitary napkins are presented in Table-6.

The fluid holding capacity of the sanitary napkins was evaluated using an in-house test method. To determine the

Fig 5 A Commercial sanitary napkin

Fig. 5 B Prototype of SCB sanitary napkin

fluid retention capacity, each napkin was weighed and mounted on a stand set at a 45° inclined angle. Blood substitute fluid was then added to the top of the absorbent layer at a rate of 5 ml/min from a 50 ml burette, with the tip of the burette adjusted to make contact with the surface of the napkin. The fluid was allowed to absorb from the top downwards until the napkin became saturated. The flow from the burette was stopped when the first drop of fluid began to drip from the napkin. The burette reading was recorded, and the fluid holding capacity was calculated in terms of g/g. The fluid holding capacity of both commercial branded napkins and SCB napkins is provided in Table-7.

Table-6 Pressure test of sanitary napkins

Brands	Volume of fluid (ml)	Pressure (Weight-Kg)	Observation
Whisper	30	1.0	No leakage
Stay free	30	1.0	No leakage
Pro ease	30	1.0	No leakage
Sofy	30	1.0	No leakage
Paree	30	1.0	No leakage
SCB napkin	30	1.0	No leakage

Table 6 demonstrates that all five commercial sanitary napkins, as well as the SCB napkin, comply with leakage protection standards. The commercial napkins utilize a polyethylene sheet as a barrier to prevent leakage, while the SCB napkin employs a hydrophobic cotton fabric in its outer layer to serve the same purpose.

Table-7 Fluid holding capacity of napkins

Brands	Weight of napkin (g)	Maximum fluid holding capacity (ml)	Fluid holding capacity (ml/g)
Whisper	6.38	55	8.6
Stay free	9.10	60	6.6
Pro ease	11.26	86	7.7
Sofy	9.23	43	4.7
Paree	9.10	50	5.5
SCB napkin	10.66	60	5.7

Table 7 indicates that Whisper exhibits the highest fluid holding capacity (8.6 ml/g) with the lowest weight of 6.33 g per specimen, attributable to the use of superabsorbent polymer as the absorbent material. Pro ease demonstrates a fluid holding capacity of 7.7 ml/g, accompanied by the highest specimen weight of 11.2 g. SCB napkins show a fluid holding capacity of 5.7 ml/g, which surpasses that of Paree and Sofy. The highest fluid holding capacity per specimen is observed in Pro ease (86 ml), followed by SCB napkins (60 ml). All other napkins exhibit lower fluid holding capacities than SCB napkins.

3.8 Liquid strike through time

Liquid strike-through time refers to the duration required for blood to penetrate the napkin at the dry stage. To perform this test, the napkin was placed on a plain glass plate to allow for clear observation of any changes occurring in the material. Two drops of artificial blood were applied to the sample using a syringe. The timer was started when the blood droplets made contact with the napkin and was stopped once the drops were no longer visible on the napkin's surface.

3.9 Wet back strike through time

Wet back strike-through time refers to the duration required for blood to penetrate the napkin when it is fully saturated. A colourless synthetic blood solution was prepared, and 10 ml of this solution was applied to the napkin using a syringe to thoroughly wet it. Two drops of coloured synthetic blood were then added to the napkin using a syringe, and the time taken for the blood drops to disappear from the top layer of the napkin was recorded. The liquid strike-through time and wet back strike-through time for several commercial napkins and SCB napkins are presented in Table 8.

Table-8 Liquid strike through and wet back strike through time of napkins

Brands	Liquid strike through time (Sec)	Wet back strike through time (Sec)
Whisper	2.7	18
Stay free	1.8	2.7
Pro ease	2.9	0.9
Sofy	3.0	2.0
Paree	2.6	3.0
SCB napkin	1.0	0.5

Table 8 shows that SCB napkins exhibit lower liquid strike-through time and wet back strike-through time compared to all other commercial napkins. This indicates that SCB napkins have a faster absorption rate than the other napkins, both under dry and wet conditions."

3.10 Analysis of Eco parameters

A comparative study of commercial sanitary napkins and SCB napkins was conducted with respect to their eco-friendliness. Various tests, including the analysis of Phthalates, Bisphenol A, Formaldehyde, and Butylated Hydroxy Toluene, among others, were performed on all the sanitary napkins. The eco-parameters of five commercial sanitary napkins and SCB napkins are presented in Table 9.

Table-9 Eco parameters of SCB napkin and commercial napkins

Parameters	Whisper	Stay free	Pro ease	Softy	Paree	SCB
pH	6.8	7.1	7.3	7.2	7.5	7.2
Phthalates (mg/kg)	ND	DNOP: 98.5	DBP: 377.4 DEHP:20.3	DNOP : 78.3	DNOP:108.2	ND
Bis phenol A (mg/kg)	1.4	0.54	ND	2.7	2.6	ND
Formaldehyde (mg/kg)	ND	ND	ND	ND	ND	ND
BHT (mg/kg)	848.9	1153.0	812.6	1030.7	766.8	ND
Bio-degradability (90 days)	Non bio-degradable	Non bio-degradable	Non bio-degradable	Non bio-degradable	Non bio-degradable	Fully bio-degradable

Abbreviations:
ND: Not Detected, DOP: Di-Octyl Phthalate, DBP: Di-Butyl Phthalate, DNOP: Di-N-Octyl Phthalate, DEHP: Di-Ethyl Hexyl Phthalate, BHT: Butylated Hydroxy Toluene.

Table 9 shows that the pH of the extract from all commercial napkins and SCB napkins falls within the range of 6.0 to 8.5, which complies with the IS 5405 specification. Formaldehyde was not detected in any of the napkins. Phthalates were detected in four of the commercial sanitary napkins, likely originating from the plastic components or adhesives used in the napkins. Similarly, trace amounts of Bisphenol A were detected in four commercial napkins, which could be a result of contamination from the packaging materials. All the commercial sanitary napkins tested contained BHT, which is likely sourced from the plastic or polymer components of the napkins. All five commercial napkins tested were non-biodegradable due to the presence of plastic and polymer materials. In contrast, SCB sanitary napkins were found to be fully biodegradable and compliant with all eco-friendly parameters, as they do not contain any plastic materials."

3.11 Size and dimensions of napkins

A dimension of the commercial sanitary napkins and SCB napkins were measured as per ASTM 1777 and is given in Table- 10.

According to the standard, the dimensions of sanitary napkins must not be less than 140 mm in length, 45 mm in width, 2.0 g in weight, and 1.0 mm in thickness. All the tested commercial napkins, as well as SCB napkins, comply with these specified dimensions.

3.12 Air permeability

The air permeability of five branded commercial sanitary napkins and SCB napkins was measured according to IS 11056, and the results are presented in Table 11. Air permeability refers to the breathability of the material; the higher the air permeability, the greater the comfort level.

Table-10 Dimensions of sanitary napkins

Parameters	Whisper	Stay free	Pro ease	Softy	Paree	SCB
Length (cm)	30	25	29	28	27	30
Width (cm)	7	7	7	7	7	10
Thickness (mm)	2.14	8.48	6.71	5.90	6.90	1.32
Weight (g)	6.46	8.56	11.28	9.25	8.90	10.60

Table-11 Air permeability of sanitary napkins

	Whisper	Stay free	Pro ease	Softy	Paree	SCB
Top portion	0.11	0.23	1.00	1.43	0.89	7.28
Middle portion	0.30	0.42	0.97	2.30	0.64	6.11
Bottom portion	0.33	0.93	0.28	2.90	0.36	6.34
Mean $ft^3/ft^2/min$	0.25	0.53	0.75	2.21	0.63	6.57

Table 11 highlights that all branded commercial sanitary napkins exhibit significantly lower air permeability compared to SCB napkins. The average air permeability of the commercial napkins ranges from 0.25 to 2.21 $ft^3/ft^2/min$, while the SCB napkins demonstrate a higher value of 6.57 $ft^3/ft^2/min$. The lower air permeability of commercial sanitary napkins can be attributed to the inner perforated polypropylene layer and the outer polyethylene layer, both of which serve as barriers to air flow. In contrast, SCB napkins feature an inner layer of absorbent cotton gauze and an outer layer of hydrophobic cotton fabric, both of which possess air porosity.

3.13 User panel assessment

User trials are essential for assessing the overall performance of a product. Two sets of commercial napkins (representing five different brands) and two sets of SCB napkins were provided to ten panel members for feedback. Each panel member was also given a set of questionnaires to provide their unbiased evaluations.

3.14 End user feedback summary

Feedback was collected from ten user panel members, and the summarized responses are as follows:

- 90% of the panel members reported that the overall performance of SCB sanitary napkins is comparable to that of the branded napkins available in the market.

- 80% of the panel members expressed the opinion that SCB napkins are fully leak-proof and on par with branded products in this regard.

- All panel members indicated that the comfort level of SCB napkins is superior to that of branded napkins, attributing this to the use of cotton fabric in both the inner and outer layers, as opposed to thermoplastic sheets used in branded versions.

- No panel members reported experiencing any skin rashes or irritations after using SCB napkins.

- All members highlighted that SCB napkins possess excellent absorbent properties and are durable for use.

- 20% of the panel members suggested that SCB napkins could benefit from improvements in shape and appearance to better compete in the commercial market."

Conclusions

In the present study, laboratory-scale sugarcane bagasse-based sanitary napkins were developed. SCB sanitary napkins present a promising solution, offering advantages in terms of cost-effectiveness, hygiene, and sustainability. A 1.0% NaOH solution is sufficient to convert bagasse into a soft, absorbent pulp, which can effectively replace the superabsorbent polymers used in branded commercial napkins. The SCB pulp sheet has proven to be a viable alternative for the manufacturing of biodegradable sanitary napkins. The developed SCB napkins demonstrated their efficacy through a series of laboratory tests. Absorbency tests confirmed that SCB napkins exhibit excellent fluid absorption capacity, outperforming several commercial sanitary napkins. Additionally, the SCB napkin was found to be free of toxic substances and fully biodegradable, as no synthetic materials were used during production. Since bagasse is an agricultural waste product, the conversion of this material into a value-added product using green technology represents the novelty of this project. The SCB napkin can be economically produced by rural women, particularly in regions with a sugarcane industry. Overall, this project paves the way for entrepreneurs to develop affordable, eco-friendly, and sustainable sanitary napkins, providing a new avenue for economic empowerment and environmental sustainability.

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Conflict of Interest

Authors hereby declare that there is no conflict of interest for publishing this paper. The findings published in this paper are fully authentic and based on the R&D work conducted in BTRA.

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