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ABSORBENCY AND PERFORMANCE INDICES OF BIODEGRADABLE ECO-FRIENDLY MATERIALS USED FOR REUSABLE MENSTRUAL PADS

***[1]Rajah, A. S., [1]Yunusa, U., [2]Tashi, F, T., [3]Tukuntawa, A. S. and [2]Abdullahi, S. O.**
[1]Department of Nursing Science, Faculty of Allied Health Sciences, Bayero University, Kano, Nigeria
[2]Department of Nursing, College of Nursing Sciences, Kano, Nigeria.
[3]School of Post Basic Nursing, National Orthopaedic Hospital, Dala-Kano, Nigeria
***Corresponding Author:** Amina Suleiman Rajah asrajah.nur@buk.edu.ng; +2347037550409
ORCID: https://orcid.org/0000-0002-3506-2098

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ABSTRACT

Background: Menstrual poverty remains a significant challenge in low- and middle-income countries, where many individuals lack access to affordable and effective menstrual products.

Aim: The research aimed to assess the absorbency and various performance indices of different biodegradable materials used in reusable menstrual pads.

Methodology: The research was based on the methodology highlighted by Foster and Montgomery, where absorbency was measured by evaluating the dry weight, wet weight, weight absorbed and amount absorbed in millilitres. The study utilized real blood samples provided by a blood bank for the absorbency test to ensure the relevance of the results. Statistical analyses, including ANOVA and Tukey's HSD post-hoc comparisons, were performed to determine significant differences in absorbency among the pad types.

Result: The cotton + bamboo fleece pads exhibited the highest absorbency with an absorbency index of 7.0 ± 0.3, outperforming other combinations. Bamboo fleece + cotton terry and bamboo + bamboo fleece pads had the lowest absorbency, with indices of 2.4 ± 0.2 and 2.5 ± 0.2, respectively.

Conclusion: The study concludes that reusable menstrual pads made from cotton and bamboo Fleece offers superior absorbance compared to other combinations. These findings support the development of effective and sustainable menstrual products. Future research should standardize testing methodologies and further explore the impact of fluid characteristics on absorbency to enhance product comparability and performance.

Keywords: Menstrual hygiene management, biodegradable materials, absorbency, reusable menstrual pads, sustainable products

INTRODUCTION

Menstruation is a normal and healthy aspect of life for women and girls around the world, affecting about 1.8 billion women each month [United Nations International Children's Emergency Fund (UNICEF), 2020]. Yet, an alarming 500 million women and girls globally do not have access to essential menstrual hygiene resources, including safe and sanitary menstrual products (Anaba *et al.*, 2022; World Health Organization, 2022). Menstrual hygiene management (MHM) refers to the use of clean materials that can be changed privately, safely, and hygienically as often as required throughout menstruation (UNICEF, 2020).

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Women in low- and middle-income countries (LMIC) often struggle with menstrual hygiene management due to the scarcity of affordable sanitary products (Foster and Montgomery, 2021a). This lack of access can increase the risk of urinary and reproductive tract infections, which may lead to fertility issues and other health complications (Hennegan *et al.*, 2017). Additionally, the high cost of sanitary products limits girls' ability to attend school, contributing to gender imbalance in schools. For instance, 66% of girls in Africa miss school during their menstrual periods (Foster and Montgomery, 2021a). Lowering the cost and improving the quality of sanitary products could significantly boost school attendance, helping girls to complete their education (Tiku, 2020).

A key concern in LMICs, which has not been adequately addressed in many studies, is the absorbency of reusable menstrual pads (RMPs). In these settings, where access to safe, affordable, and effective menstrual products is already limited, there is apprehension about whether RMPs can effectively manage menstrual flow throughout the day without causing leakage or discomfort (Achuthan *et al.*, 2021; Fader *et al.*, 2007; Van Eijk *et al.*, 2021). Many women and girls express concerns about the reliability of these pads during heavy flow days, which can lead to anxiety about leakage, school absenteeism, and social stigma (Alam *et al.*, 2022; Hennegan *et al.*, 2017; Sumpter and Torondel, 2013).

Despite the known health and educational benefits of effective menstrual hygiene management, many women and girls in low- and middle-income countries continue to face significant barriers due to the high cost and limited availability of sanitary products (UNICEF, 2020). Traditionally, menstrual management in low and middle income countries has relied on less effective materials such as old clothes, paper, and leaves, which often fail to meet hygiene needs and contributes to school absenteeism (UNICEF, 2020). Additionally, inadequate disposal facilities lead to environmental pollution, as menstrual products are often discarded inappropriately (Foster and Montgomery, 2021b; Warashinta *et al.*, 2021).

The potential of biodegradable materials like bamboo, cotton, cotton fleece, cotton flannel, bamboo wadding, cotton terry and banana fibers to address these challenges is promising (Barman *et al.*, 2018; Foster and Montgomery, 2021a; Hand *et al.*, 2023; Lather and Singh, 2021; Srikavi and Mekala, 2021). These eco-friendly alternatives could offer both effective menstrual management and a solution to the environmental impact of menstrual waste (Foster and Montgomery, 2021b).

Therefore, this study aims to evaluate the absorbency of biodegradable materials used in RMPs, and given the limited availability of reliable menstrual products in these regions, assessing the absorbency of these materials is essential to determine their suitability as a sustainable and effective solution for menstrual hygiene management.

Eco-friendly Materials for Reusable Menstrual Pads

The findings of a previous scoping review conducted by the researchers revealed that a range of novel, eco-friendly materials can be utilized in RMPs, offering a sustainable alternative to conventional disposable products (Rajah *et al.*, 2024). These materials are categorized into three essential layers integral to RMP design: the top layer, core, and bottom layer. For the top layer, which must be soft, comfortable, and breathable, the review identified materials such as bamboo fiber, banana fiber, organic cotton fibers, cotton flannel, jute, non-woven bamboo, bamboo pulp, water hyacinth, 100% knitted cotton fabric, flax fibers, kenaf, TENCEL® Biosoft (lyocell fiber), papaya fibers, and papyrus (Rajah *et al.*, 2024).

The core layer, which requires high absorbency and durability, includes materials such as cotton terry cloth, linen, hemp cloth, bamboo wadding, cotton fleece, poly-wadding, bamboo kun, jute, Sansevieria trifasciata plant fibers, kenaf, chitosan fibers, and wool. For the bottom layer, designed to be water-repellent, the review highlighted materials like polyester/nylon plain weave fabric, polyurethane laminate (PUL), polyethylene, polypropylene, corn starch-based bio-plastic sheets, and poly lactic acid (PLA) fiber.

MATERIALS AND METHODS

The methodology for this study involves evaluating the absorbency of reusable menstrual pads made from novel eco-friendly materials identified in a previous scoping review. This evaluation focuses on three primary tests as highlighted by Foster and Montgomery (2021b): Liquid Strike-Through, Wet Back Strike-Through, and Absorbent Capacity (amount and weight). The tests are performed in triplicates to ensure precision and reliability in the results. The materials used in this experiment include various reusable menstrual pads made from different eco-friendly materials. These pads feature combinations of five top layer materials (cotton flannel, bamboo fleece, cotton fleece, cotton-bamboo blend), three core materials (bamboo wadding, cotton terry cloth, bamboo fleece), and a polyurethane laminate (PUL) bottom layer. A control group of commercially available disposable sanitary pads was also included. For the tests, human blood, obtained from the blood bank and set to expire on the day of the experiment, was used as a substitute for synthetic blood to more accurately simulate menstrual fluid. Other materials include a clean glass plate, stopwatch, syringe, weighing balance, disposable gloves, and data recording sheets.

Sample Preparation

Each of the 48 pads used was labelled with a unique identifier corresponding to its material combination. The weight of each dry pad was recorded to establish a baseline measurement for comparison.

Absorbent Capacity Test (Amount)

A dry pad was placed on the clean glass plate, and drops of blood were added to the center of the top layer until the pad began to leak from the sides or bottom. The total amount of blood absorbed before leakage was measured and recorded (Foster and Montgomery, 2021a; Shanmuga *et al.*, 2023).

Absorbent Capacity Test (Weight)

Immediately following leakage, the saturated pad was weighed, and the weight was recorded. This measurement was used to calculate the absorbency of each pad (Foster and Montgomery, 2021b).

Figure 1: Reusable Pad Saturated with Blood

Figure 2: Saturated Reusable Pad Weighing

Liquid Strike-Through Test

Sterile gloves were worn to maintain hygiene. Each dry pad was placed on the clean glass plate, and a single drop of blood was carefully applied to the center of the top layer using a syringe. The stopwatch was started immediately upon application. The watch was stopped when the blood penetrated through to the top layer of the pad. The time taken for this process was recorded for each pad, and the procedure was repeated for all pads (Bachra *et al.*, 2021).

Wet Back Strike-Through Test

Following the same initial steps as the Liquid Strike-Through Test, 10 ml of blood was evenly distributed and allowed to saturate the pad for 5 minutes. After this period, a second drop of blood was added to the pad, and the time taken for it to penetrate the saturated pad was recorded. This procedure was repeated for all pads (Bachra *et al.*, 2020; Foster and Montgomery, 2021b).

Calculations

The absorbency index was calculated using the formula:

$$\text{Absorbency Index} = \left(\frac{\text{Total amount of liquid absorbed (ml)}}{\text{Weight of dry pad (g)}}\right)$$

Figure 3: Liquid Strike-through Test

Figure 4: Wet Back Strike-through Test

STATISTICAL ANALYSIS

Descriptive statistics were computed to summarize the central tendency and dispersion of absorbency measures. This included calculating means, standard deviations, and ranges for the absorbency index of different pad types. The recorded data, including time for strike-through and weights of dry and saturated pads, were compiled into a table for analysis. The average and standard deviation for strike-through time and absorbency index were calculated for each pad type based on material combinations. Data trends and significant differences in absorbency between various materials were analyzed. To determine whether there were significant differences in absorbency among the different pad types, inferential statistics (ANOVA) was performed. Post-hoc comparisons using Tukey's HSD (Honestly Significant Difference) test were conducted to identify which specific pad types differed from one another.

Ethical Considerations

Ethical approval with NHREC Approval Number: NHREC/BUK-HREC/481/10/23II was obtained from the Health Research Ethics Committee (HREC), Bayero University, Kano. The research adhered to all established ethical standards for the use of biological materials. All used pads and human blood were disposed off according to proper laboratory waste disposal protocols to ensure safety and environmental protection.

RESULTS

Table 1 highlights the absorptive capacity of various menstrual pad designs, comparing different top layers and absorbent cores. Among the tested combinations, the pad with a Cotton top layer and Bamboo Fleece core exhibited the highest fluid absorption, reaching 207 ml. In contrast, the pad with a Bamboo top layer and Bamboo Fleece core had the lowest absorbency at 55 ml. The disposable pad, used as a benchmark, showed an absorption capacity of 66 ml, which is notably lower than that of the reusable pads.

The data reveal that pads incorporating materials such as Cotton + Bamboo Fleece and Cotton Fleece + Bamboo Fleece exhibit the highest absorbency indices of 7.0 ± 0.3 and 6.9 ± 0.2, respectively. These pads demonstrate superior performance, with high amounts of blood absorbed (190 ml and 207 ml, respectively) compared to other combinations. On the other end of the spectrum, the pads with the lowest absorbency indices are Bamboo Fleece + Cotton Terry and Bamboo + Bamboo Fleece, with indices of 2.4 ± 0.2 and 2.5 ± 0.2, respectively. Despite having substantial amounts of weight absorbed, these pads perform less efficiently in terms of absorbency index.

When compared to the disposable pad, which has an absorbency index of 6.0 ± 0.2, the top-performing reusable pads such as Cotton + Bamboo Fleece and Cotton Fleece + Bamboo Fleece exhibit slightly higher indices, indicating that they can absorb and retain liquid more effectively.

Table 1: Total Absorptive Capacity

S/N	Pads	Dry Weight (g) ± SD	Wet Weight (g) ± SD	Weight Absorbed (g)	Amount Absorbed (ml)	Absorbency Index
1	Bamboo Fleece + Cotton Terry	45 ± 0.5	165 ± 1.2	120 ± 1.0	110 ± 1.5	2.4 ± 0.2
2	Cotton Fleece + Cotton Terry	44 ± 0.6	241 ± 1.5	197 ± 1.2	189 ± 2.0	4.3 ± 0.3
3	Cotton + Cotton Terry	43 ± 0.5	262 ± 1.3	219 ± 1.0	170 ± 1.8	4.0 ± 0.2
4	Bamboo + Cotton Terry	36 ± 0.7	181 ± 1.4	145 ± 1.1	130 ± 1.6	3.6 ± 0.3
5	Cotton Flannel + Cotton Terry	41 ± 0.6	212 ± 1.3	171 ± 1.2	145 ± 1.7	3.5 ± 0.2
6	Bamboo Fleece + Bamboo Fleece	31 ± 0.5	135 ± 1.2	104 ± 1.1	92 ± 1.4	3.0 ± 0.2
7	Cotton + Bamboo Fleece	27 ± 0.4	218 ± 1.1	191 ± 1.0	190 ± 1.5	7.0 ± 0.3
8	Cotton Fleece + Bamboo Fleece	30 ± 0.6	247 ± 1.2	217 ± 1.1	207 ± 1.6	6.9 ± 0.2
9	Bamboo + Bamboo Fleece	22 ± 0.4	89 ± 1.0	67 ± 0.9	55 ± 1.2	2.5 ± 0.2
10	Cotton Flannel + Bamboo Fleece	23 ± 0.5	182 ± 1.1	159 ± 1.0	145 ± 1.5	6.3 ± 0.3
11	Bamboo Fleece + Bamboo Wadding	32 ± 0.6	168 ± 1.2	136 ± 1.1	124 ± 1.6	3.9 ± 0.2
12	Cotton Fleece + Bamboo Wadding	31 ± 0.5	135 ± 1.1	104 ± 1.0	95 ± 1.4	3.1 ± 0.2
13	Cotton + Bamboo Wadding	31 ± 0.4	201 ± 1.2	170 ± 1.1	170 ± 1.5	5.5 ± 0.3
14	Bamboo + Bamboo Wadding	25 ± 0.6	187 ± 1.3	162 ± 1.2	150 ± 1.6	6.0 ± 0.3
15	Cotton Flannel + Bamboo Wadding	29 ± 0.5	129 ± 1.1	100 ± 1.0	89 ± 1.5	3.1 ± 0.2
16	Disposable Pad	11 ± 0.4	92 ± 1.0	81 ± 0.8	66 ± 1.3	6.0 ± 0.2

The Levene's statistic, indicates a p-value of 1.000 across all measures, suggesting that the variances in absorbency are equal across the different pad types. This supports the validity of the ANOVA results, as the assumption of homogeneity of variances is met. The ANOVA itself reveals a significant difference in absorbency between pad types, with an F-value of 128.474 and a p-value of .000, which indicates that at least one pad type differs significantly in absorbency compared to others.

Post-hoc comparisons using Tukey's HSD test reveal specific differences between pad types. The test reveals distinct groupings of pad types based on their absorbency levels. The lowest absorbency pads, such as Bamboo Fleece + Cotton Terry and Bamboo + Bamboo Fleece, fall into the initial subsets, with values ranging from 2.40 to 2.50. The highest absorbency is observed in Cotton + Bamboo Fleece, Cotton Fleece + Bamboo Fleece, Cotton Flannel + Bamboo Fleece, Bamboo + Bamboo Wadding with values ranging from 6.00 to 7.00, indicating these combinations have significantly superior absorbency compared to others, including disposable pads.

Table 2: ANOVA

Absorbency Index	ANOVA				
	Sum of Squares	df	Mean Square	F	P-value
Between Groups	113.218	15	7.548	128.474	0.0001
Within Groups	1.880	32	.059		
Total	115.098	47			

The liquid strike through test (Figure 5) presents the time taken for blood to strike through various reusable menstrual pad combinations. Notably, the combinations with the lowest strike-through times, such as Cotton + Bamboo Wadding (1.5 seconds) and Cotton Fleece + Bamboo Wadding (2 seconds), indicate that these pads offer rapid absorption, which can significantly reduce the risk of leakage and discomfort. These fast strike-through times suggest that these materials quickly contain liquid, providing an immediate barrier and maintaining user comfort.

On the other hand, combinations with higher strike-through times, like Bamboo Fleece + Bamboo Wadding (477 seconds) and Bamboo Fleece + Cotton Terry (346 seconds), show slower absorption rates.

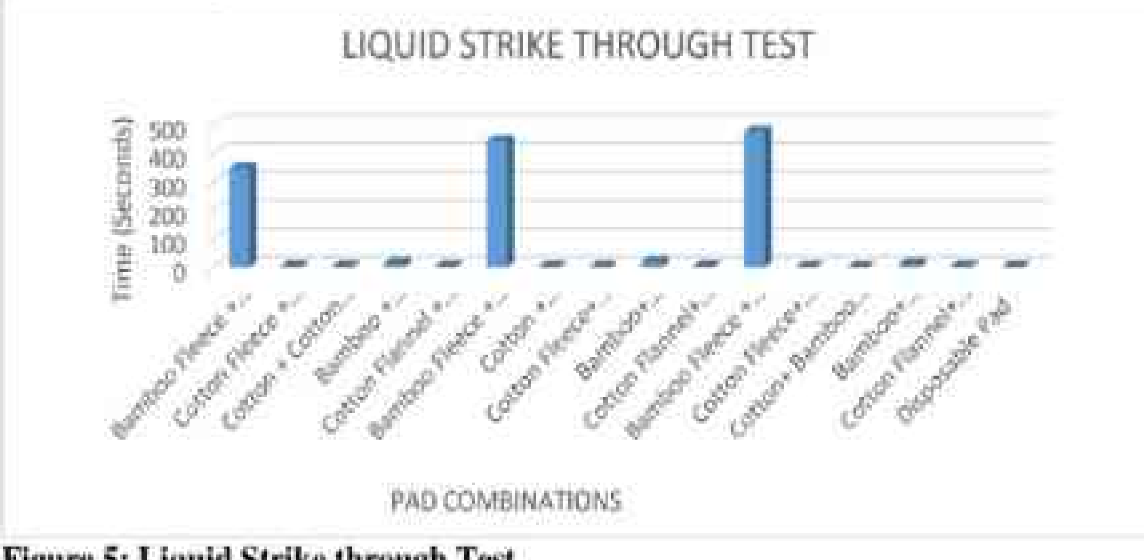

Figure 5: Liquid Strike through Test

The Wet Back Strike-Through Test results reveal that pads with Cotton Fleece + Bamboo Wadding (0.3 seconds) and Cotton + Bamboo Wadding (0.5 seconds) show the fastest penetration times, significantly outperforming others, including the disposable pad at 0.6 seconds. Conversely, the Bamboo Fleece + Bamboo Fleece combination, with a much slower penetration time of 141 seconds, indicates poor performance in terms of absorbing liquid once saturated, potentially leading to increased leakage and discomfort.

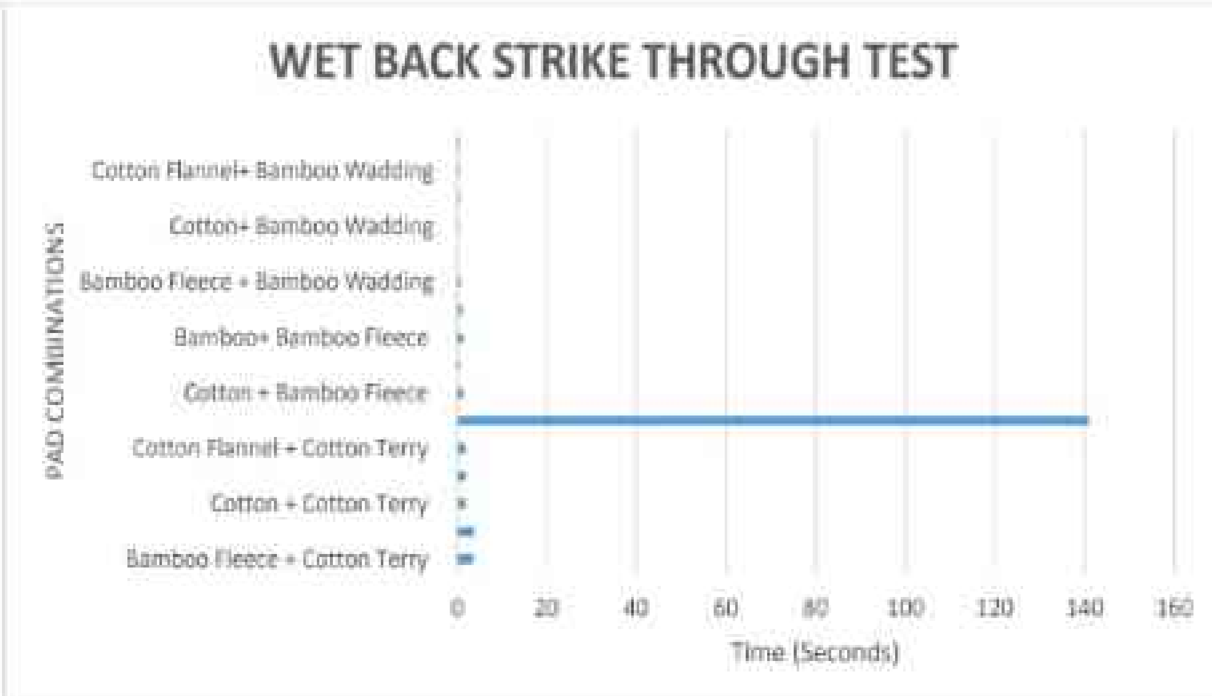

Figure 6: Wet Back Strike Through Test

DISCUSSION

The aim of the present study was to evaluate the absorbency of various biodegradable materials for reusable menstrual pads, with a focus on their performance in low- and middle-income communities. Our findings demonstrate that pads incorporating a Cotton top layer and Bamboo Fleece core exhibit the highest absorbance rate, up to 207 ml of fluid. The ANOVA results indicate significant differences in absorbency among the tested pad types. Post-hoc comparisons using Tukey's HSD test further reveal distinct groupings of pad types based on their absorbency levels. The highest absorbencies were observed in Cotton + Bamboo Fleece, Cotton Fleece + Bamboo Fleece, Cotton Flannel + Bamboo Fleece, and Bamboo + Bamboo Wadding, with indices ranging from 6.00 to 7.00. This is in line with the study by Foster and Montgomery (2021a, 2021b), which identified Bamboo wadding as having the highest absorptivity index (7.86), which aligns with our findings that Bamboo + Bamboo Wadding exhibits high absorbency (6.0 ± 0.3). However, our study also shows that some combinations of top player with bamboo wadding- Cotton + Bamboo Wadding {5.5 ± 0.3} and Bamboo Fleece + Bamboo Wadding {3.9 ± 0.2}- had lower absorption index than reported by the 2 studies of Foster and Montgomery (2021a, 2021b). This discrepancy may be attributed to viscosity and characteristics of the gelatine solution used for testing. In our study, human blood was used, which has a higher viscosity and more complex properties compared to blood substitutes used in other studies. This difference may influence the absorbency outcomes, as natural blood can interact with the materials differently than synthetic substitutes.

The use of human blood provides a more accurate representation of menstrual fluid conditions, but it also introduces variability that can affect results.

Similarly, the study by Shibly *et al.* (2021) reported that commercial pads and material blends like Cotton with Viscose exhibited competitive absorbency. Our results support this observation, as the absorbency of some reusable pads, particularly those with Cotton + Bamboo Wadding, matches or even exceeds that of disposable pads. Notably, our data show that the Cotton + Bamboo Wadding combination has a higher absorbency index than the disposable pad (6.0 ± 0.2), highlighting the potential of reusable options to provide effective and sustainable alternatives.

Additionally, our findings regarding strike-through times reveal that the top-performing reusable pads, such as Cotton + Bamboo Wadding (1.5 seconds) and Cotton Fleece + Bamboo Wadding (2 seconds), demonstrate faster absorption compared to the disposable pad (3 seconds). This quicker absorption reduces the risk of leakage and enhances comfort, aligning with Shibly *et al.*'s observation that commercial pads perform well in terms of absorption speed (Shibly *et al.*, 2021).

Conversely, Foster and Montgomery (2021a, 2021b) reported a low absorptivity index for Cotton terry cloth, with values of 0.84 ± 0.15. In our study, the highest absorbency index for Cotton terry was observed in Cotton Fleece + Cotton Terry (4.3 ± 0.3), while the lowest was in Bamboo Fleece + Cotton Terry (2.4 ± 0.2). This discrepancy may be attributed to differences in material preparation, testing conditions, or measurement techniques. Notably, our study used real blood obtained from a blood bank, whereas the studies by Foster and Montgomery utilized blood substitutes. These variations in fluid characteristics could significantly impact absorbency measurements. Such discrepancies underscore the need for standardized testing methodologies to enhance comparability and provide a clearer understanding of the factors influencing material performance.

CONCLUSION

This study demonstrates that biodegradable materials, particularly the combination of cotton and bamboo fleece showed superior absorbency, outperforming the disposable pad in absorbency. Furthermore, Bamboo Fleece is more effective as a core layer than a top layer due to its slower absorption rates. This study provides valuable insights into optimizing reusable menstrual pads, showcasing their superior performance compared to disposable pads and highlighting their potential for more effective and eco-friendly menstrual hygiene solutions.

RECOMMENDATIONS

Based on the findings of this research, several recommendations can be made to improve the design and performance of biodegradable menstrual pads. To improve the design and performance of biodegradable menstrual pads, it is recommended to optimize material layering by using Bamboo Fleece as a core layer for its superior absorbency and Cotton or Cotton Fleece as top layers for quicker absorption and reduced leakage. Prioritizing materials like Bamboo Wadding for core layers further enhances performance. Standardized testing procedures should be adopted to ensure consistent and reliable results, while the environmental impact of biodegradable materials should be evaluated throughout their lifecycle. Lastly, incorporating user feedback into the design process can improve comfort and practicality, ensuring the pads meet users' needs effectively.

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Conflict of Interest

There is no conflict of interest in this project.

Author Contributions

AR contributed to the conceptualization, original draft preparation, laboratory analysis and data analysis. UY contributed to conceptualization, methodology, laboratory analysis and served as the final reviewer and editor. AT and FT participated in data collection, laboratory analysis, data analysis and manuscript writing. SA contributed to project administration, conceptualization and final draft review.

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The Effectiveness of Different Cleaning Methods on the Microbial Load of Reusable Menstrual Pads

*[1]Rajah, A. S. , [1]Yunusa, U., [2]Tashi, F, T., [3]Tukuntawa, A. S. and [2]Abdullahi, S. O.
[1]Department of Nursing Science, Faculty of Allied Health Sciences, Bayero University, Kano, Nigeria
[2]Department of Nursing, College of Nursing and Midwifery, Kano, Nigeria.
[3]School of Post Basic Nursing, National Orthopaedic Hospital, Dala-Kano, Nigeria
Correspondence: asrajah.nur@buk.edu.ng; +2347037550409

Abstract

Menstrual pads are essential hygiene products used to manage menstrual flow, ensuring comfort and dignity for menstruating individuals. Reusable menstrual pads are re-gaining popularity as a sustainable and cost-effective alternative to disposable ones. This study aimed to determine the efficacy of various cleaning methods in reducing the microbial load of reusable menstrual pads. A total of 26 samples from reusable menstrual pads were collected. The participants were directed to follow specific washing protocols as highlighted in recommendations by UNICEF (washing with water only, detergent only, bar soap only, detergent and disinfectant and detergent, disinfectant, and ironing). Samples (used reusable menstrual pads) were retrieved from participants to analyze any microbial presence on the pads themselves. Microbiological analysis was conducted to assess microbial growth on nutrient agar, chocolate agar, and Sabouraud dextrose agar. Results obtained showed low microbial load in 53.8% of the samples analyzed. All reusable menstrual pads (RMPs) washed with water only (5) were positive for bacterial culture with a count of > 100cfu/ml. Those washed with Viva detergent and May bar soap revealed a microbial count of 50-100cfu/ml. RMPs washed with Viva detergent and Dettol disinfectant, dried, and then ironed showed no significant growth or very low microbial counts compared to other cleaning methods (p-values: mesophilic bacteria, $p = 0.009$; molds, $p = 0.009$; anaerobic bacteria, $p = 0.026$; and Staphylococcus spp., $p = 0.001$). The predominant isolates are Staphylococcus species (26.9%), Lactobacillus species (26.9%), Candida species (19.2%), and Fusobacterium nucleatum (23%). The study revealed that reusable menstrual pads cleaned with water only had the highest microbial loads, while those cleaned with a combination of detergent, disinfectant, and ironing showed minimal to no microbial contamination, demonstrating this method as the most effective for ensuring hygiene and safety.

Keywords: Bacterial burden, Cleaning methods, Disinfection, Fungal load, Menstrual hygiene, Reusable menstrual pads,

INTRODUCTION

Menstruation is a natural and healthy cycle in fertile women and girls from puberty to menopause, with approximately 1.8 billion women globally experiencing it monthly (Anaba *et al.*, 2022). Ensuring optimal hygiene practices during menstruation is essential for preventing associated infections (Warashinta *et al.*, 2021). However, a staggering 500 million women and girls worldwide lack access to menstrual hygiene facilities, including safe and hygienic menstrual management materials(Anaba *et al.*, 2022). Additionally, managing menstruation effectively and hygienically can be a significant challenge, especially in low-income settings (Hennegan *et al.*, 2017). Limited access to clean water, sanitation facilities, and appropriate menstrual products often leads to negative health consequences, hinders education opportunities, and reduces overall well-being (UNICEF, 2020). Providing safe and respectful ways to manage menstruation (often referred to as Menstrual Hygiene Management or MHM) is essential for women's overall health and well-being (Hand *et al.*, 2023). Having access to safe and dignified menstruation is a fundamental right for all women and girls (UNICEF, 2020). UNICEF's vision is a world where every girl can go about her daily activities - learning, playing, and taking care of herself - without the added stress, shame, or restrictions associated with menstruation due to lack of information or supplies (UNICEF, 2020). Growing evidence based on low- and middle-income countries shows that many girls are not able to manage their menses and associated hygiene with ease and dignity(Asumah *et al.*, 2022; Kumie *et al.*, 2022).

This deprivation is even more alarming for girls and women in emergencies.

Properly managing menstruation involves the availability of absorbent materials and the provision of safe, accessible, and private sanitation facilities alongside culturally appropriate information on menstrual hygiene management (MHM)(Hand *et al.*, 2023). Despite global advancements in menstrual health awareness and the proliferation of products, many women in resource-limited settings still rely on reusable menstrual pads (RMPs) due to their cost-effectiveness and environmental sustainability (Shibly *et al.*, 2021).

RMPs are a type of menstrual product worn externally to the body in the underwear, to absorb menstrual flow and held in place usually by snaps. They are made from natural or synthetic materials (UNICEF, 2020). The materials used in RMPs, such as organic cotton, bamboo, and other eco-friendly fabrics, are gentle on the skin, highly absorbent, and free from harmful chemicals often found in disposable pads. After use, they are washed, dried, and re-used (UNICEF, 2020). RMPs are re-gaining popularity as a sustainable and cost-effective alternative to disposable options. These pads are designed to be durable and can be used repeatedly over a long period, which makes them an economical choice for women and girls, especially in low-income countries (World Bank Group, 2023).

Despite these benefits, the potential for microbial growth on RMPs raises concerns about user safety and infection risks. The unique environment created by menstrual blood and the potential for improper cleaning practices could lead to the proliferation of bacteria and fungi, potentially causing urinary tract infections (UTIs), yeast infections, and other health complications (Anderhell & Sundberg, 2019).

Additionally, the use of RMPs poses potential health risks if not properly managed. Inadequate washing and drying practices can lead to the proliferation of bacteria and other pathogens, potentially increasing the risk of urinary tract infections, vulvovaginitis, and other reproductive health issues (Anderhell & Sundberg, 2019). The importance of evaluating the microbial safety of these products cannot be overstated, particularly as their use is advocated as a sustainable option in both developing and developed countries (UNICEF, 2020).

Recent studies have revealed significant knowledge gaps in the proper care and microbial safety of reusable menstrual pads (RMPs), emphasizing the lack of research on effective cleaning methods to reduce microbial growth and health risks, particularly in low- and middle-income countries (Asumah *et al.*, 2022; Parikh & Nagar, 2022; Pednekar *et al.*, 2022; Roxburgh *et al.*, 2020). This study addresses these gaps by evaluating microbial burden, infection risks, and the effectiveness of cleaning methods for RMPs, providing actionable guidelines to promote safer use and support menstrual health equity.

MATERIALS AND METHODS

Study Design

This study employed an *in vitro* (laboratory-based) approach to evaluate the microbial burden associated with RMPs and assess the effectiveness of different cleaning methods in mitigating microbial growth.

Study Population

All participants in the present study were healthy women 18-45 years old who resided in Kano, Nigeria, had a menstrual cycle of 21-30 days, and were menstruating (day 2, 3, or 4 of the menstrual cycle) at the time of sampling. The study excluded pregnant or lactating women, women with a history of pelvic inflammatory disease or recurrent UTIs, and women using any vaginal medications within the past month. Informed consent was obtained from all participants before sample collection. Participant confidentiality was ensured throughout the study. Ethical approval with NHREC Approval Number: NHREC/17/03/2018/SHREC/2024/4838 was obtained from the Health Research Ethics Committee (HREC), Ministry of Health, Kano State.

Sample Collection

Participants were recruited for sample collection and were provided with detailed information on washing and drying techniques for the RMPs. They were instructed to follow specific washing protocols as highlighted in recommendations by UNICEF (2020). A total of 26 samples were collected and analysed from the participants of the study. Five (5) samples were collected from each participant. The samples collected included RMPs washed with water only (WWO), washed with Vivo detergent only (WD), washed with May bar soap only (WBS), washed with Vivo detergent and Dettol disinfectant (WDD), and washed with Vivo detergent, Dettol disinfectant, and ironed (WDD-I) after drying in the sun. A sample of un-used RMP served as the control for the study. The samples (used RMPs) were retrieved from participants to analyze any microbial presence on the pads.

After cleaning, participants were instructed to handle the pads with clean hands and store them in sterile ziplock bags provided by the researchers. Participants washed the pads using the specified cleaning methods after their regular menstrual cycle. Researchers then retrieved the washed and dried pads for microbial analysis. This standardized collection protocol ensured consistency and reliability in sample handling, allowing for a thorough investigation of the effectiveness of different cleaning methods in reducing microbial contamination on RMPs.

Sample preparation

The samples were assigned unique identifiers and processed immediately to minimize microbial overgrowth. Each sample was aseptically removed from its sterile ziplock bag, immersed in 100 mL of buffered saline solution, and soaked for 2 minutes. The concentrated eluate was divided into several aliquots, and the analyses were performed using the membrane filtration technique (Briancesco *et al.*, 2018). Eight different groups of microorganisms/bacterial species were investigated, as highlighted by Briancesco *et al.* (2018). Thus, the membranes were incubated on various agarized media for the detection of the following microbial parameters:

The microbial analysis involved biochemical and molecular techniques to accurately identify the species present. The microbial analysis involved various organisms incubated under specific conditions to determine colony counts. Mesophilic bacteria were cultured on Plate Count Agar at 36°C for 72 hours, with total colonies counted. Fungi (molds and yeasts) were incubated on Sabouraud Dextrose Agar at 25°C for 7-10 days, and mold and yeast colonies were enumerated. Anaerobic bacteria were incubated on Plate Count Agar at 36°C in anaerobic conditions for 72 hours. Coliforms were identified on Chromogenic E. coli/Coliform (C-EC) medium at 36°C for 24 hours, with blue colonies counted. Escherichia coli colonies, both blue and fluorescent, were similarly counted using a Wood lamp. Staphylococcus spp. were identified on Baird Parker Agar at 36°C for 48 hours, with black colonies counted. Candida albicans was cultured on Biggy Agar at 36°C for 48 hours, with dark brown colonies enumerated. Finally, Pseudomonas aeruginosa was grown on Pseudomonas Agar at 36°C for 48 hours, and green-blue colonies were confirmed biochemically under a Wood lamp by identifying fluorescent and reddish-brown colonies.

Figure 1: Samples soaked in sterile peptone water

Figure 2: An overnight cultured plates (Nutrient and Heated blood agar)

Data Analysis:

The number of colony-forming units (CFUs) on each plate was used to calculate each sample's total bacterial and fungal counts. Statistical analysis was performed to compare the microbial counts (and potentially the identified species) between RMPs cleaned with different methods.

RESULTS

Table 1: Result of Microbial Analysis of Reusable Menstrual Pads

PRODUCT CODE	MESOPHILIC BACTERIA CFU/ RMP	MOLDS CFU/ RMP	ANAEROBIC BACTERIA CFU/ RMP	*STAPHYLOCOCCUS* SPP. CFU/ RMP
A1-WWO	100	5	10	<1
S3-WWO	>100	10	<50	5
F4-WWO	>100	15	<50	5
M5-WWO	>100	10	<50	5
B2-WWO	>100	15	<50	5
A1-WD	<50	<1	<1	<1
S3-WD	<50	<1	<1	<1
F4-WD	>100	<1	50	<1
M5-WD	<100	<1	<50	<1
B2-WD	>100	<1	<50	<1
A1-WBS	<100	<1	<1	<1
B2-WBS	>100	5	<1	<1
S3-WBS	>50	<1	<1	<1
F4-WBS	>100	5	<1	<1
M5-WBS	100	<1	<1	<1
A1-WDD	<50	<1	<1	<1
B2-WDD	<1	<1	<1	<1
S3-WDD	<50	<1	<1	<1
F4-WDD	<100	<1	<1	<1
M5-WDD	<1	<1	<1	<1
A1-WDD-I	NG	<1	<1	<1
B2-WDD-I	NG	<1	<1	<1
S3-WDD-I	<1	<1	<1	<1
F4-WDD-I	<1	<1	<1	<1
M5-WDD-I	NG	<1	<1	<1
Un-used RMP	<50	<1	<1	<1
Un-used RMP sterilized by autoclave	NG	<1	<1	<1

CFU: Colony Forming Units NG: No Growth

The analysis reveals significant variation in microbial growth based on the cleaning method used. A large proportion of the pads (53.3%) showed no significant microbial growth when cleaned with effective methods such as detergent, disinfectant, and ironing, demonstrating the importance of proper cleaning techniques. Pads cleaned with water exhibited consistently high microbial counts, especially for mesophilic bacteria, often exceeding 100 CFU/RMP. Detergent cleaning alone resulted in a reduction in microbial load, though some samples still showed elevated counts. Bar soap yielded intermediate results, with microbial levels lower than water-only cleaning but still relatively high.

The most effective method for microbial reduction was the combination of detergent and disinfectant, which led to significant reductions in microbial growth, with most samples showing mesophilic bacterial counts below 50 CFU/RMP. Adding ironing to this cleaning method resulted in minimal to no microbial growth, with several samples showing no significant growth (NSG), indicating near-complete elimination of microbes. Molds, anaerobic bacteria, and *Staphylococcus spp.* were either undetectable or showed extremely low counts (<1 CFU/RMP) with this method. Unused pads exhibited low microbial counts, typically under 50 CFU/RMP, and pads sterilized by autoclaving showed no significant microbial growth, confirming the sterilization method's effectiveness in eliminating microbes.

Table 2: Chi-Square Test Results for All Dependent Variables

Dependent Variable	Test	Value	df	Asymptotic Significance (p-value)
Mesophilic Bacteria	Pearson Chi-Square	32.500	16	0.009
	Likelihood Ratio	35.467	16	0.003
	Linear-by-Linear Association	16.138	1	0.000
	N of Valid Cases			25
Molds	Pearson Chi-Square	26.667	12	0.009
	Likelihood Ratio	27.474	12	0.007
	Linear-by-Linear Association	10.446	1	0.001
	N of Valid Cases			25
Anaerobic Bacteria	Pearson Chi-Square	23.235	12	0.026
	Likelihood Ratio	26.881	12	0.008
	Linear-by-Linear Association	13.863	1	0.000
	N of Valid Cases			25
Staphylococcus spp.	Pearson Chi-Square	19.048	4	0.001
	Likelihood Ratio	16.979	4	0.002
	Linear-by-Linear Association	9.143	1	0.002
	N of Valid Cases			25

The Chi-Square test results show that the cleaning methods significantly impact mesophilic, molds, anaerobic, and Staphylococcus spp growth. The p-values for the different microbial types are as follows: for mesophilic bacteria, $p = 0.009$; for molds, $p = 0.009$; for anaerobic bacteria, $p = 0.026$; and for Staphylococcus spp., $p = 0.001$. These p-values indicate that the null hypotheses, which suggested no difference in microbial growth across cleaning methods, are rejected for all four microbial types because the p-values are less than the significance level of 0.05. Therefore, the cleaning method significantly influences microbial contamination levels, emphasizing the importance of selecting effective cleaning methods to reduce contamination and enhance the hygiene of reusable menstrual pads.

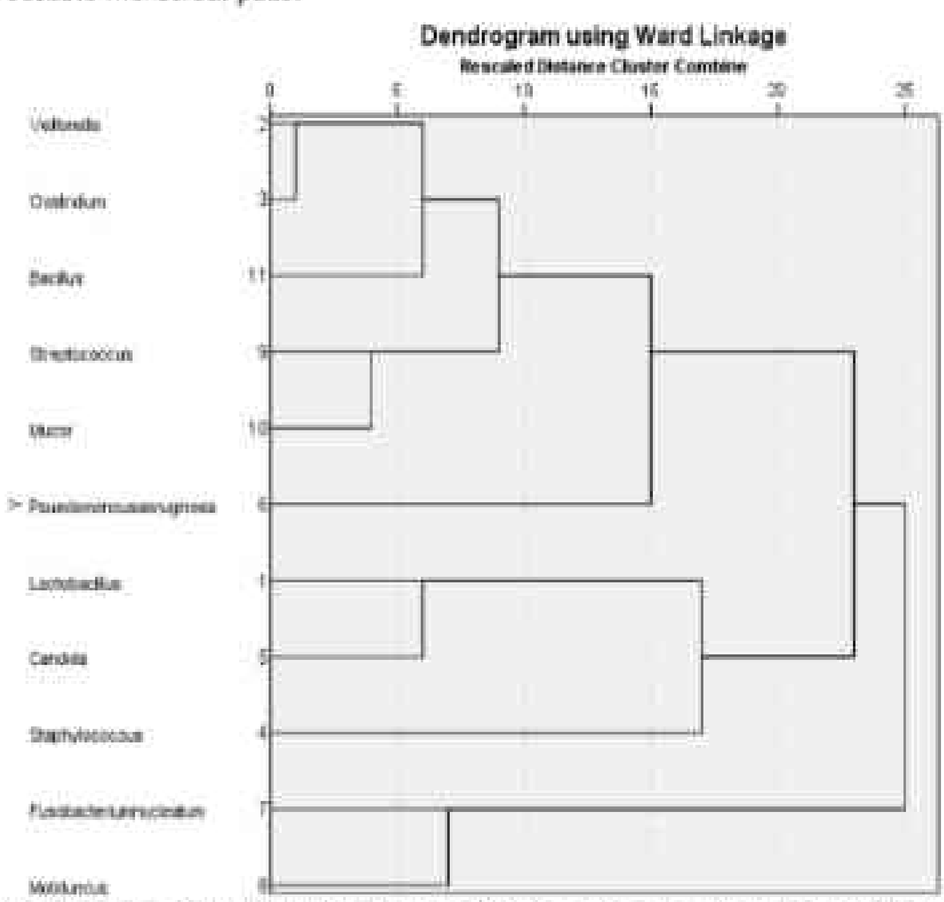

Figure 3: Dendrogram of Microbial Species Identified from the Analysed Reusable Menstrual Pads

The dendrogram illustrates the hierarchical clustering of microbial species identified from reusable menstrual pads based on their similarities and frequency of occurrence. The y-axis represents the rescaled distance between clusters, indicating how similar or dissimilar each cluster is. The first significant separation occurs with *Lactobacillus*, which forms its distinct cluster. Notably, *Lactobacillus* had the highest occurrence, appearing 6 times across the samples, highlighting its dominance in the microbial community. As the clustering progresses, *Veillonella* and *Clostridium*, which appeared once each, form a group with other species, such as *Bacillus*, which also appeared once. These patterns suggest shared microbial characteristics among these species despite their lower frequency of occurrence.

The clustering also highlights species with moderate frequencies. For instance, *Staphylococcus* and *Candida*, each identified 5 times, merge in later stages of the dendrogram with species like *Pseudomonas aeruginosa*, which appeared 4 times, indicating potential co-occurrence or environmental similarities. At the same time, less frequent species such as *Fusobacterium nucleatum* and *Mobiluncus*, each identified 3 times, form a distinct cluster, suggesting a shared ecological niche on the reusable pads.

DISCUSSION

The effectiveness of different cleaning methods revealed significant variability in microbial presence. Pads washed with detergent and disinfectant and then ironed exhibited either minimal bacterial colonies or no microbial growth, demonstrating the superiority of this method in eliminating microorganisms. In contrast, other cleaning methods, such as washing with water only, detergent only, or bar soap only, showed varying degrees of microbial persistence. This result suggests that the combination of disinfectants and heat treatment (ironing) provides an effective strategy for reducing microbial contamination. The implications of these findings are crucial for promoting proper hygiene practices, especially in low-resource settings, to minimize health risks associated with reusable menstrual pads. Comparisons with previous studies, such as Veeh et al. (2003), further support the effectiveness of advanced cleaning and sterilization techniques in managing microbial contamination. However, studies such as Briancesco et al. (2018) highlight the limitations of relying solely on conventional cleaning methods, emphasizing the importance of educating users on optimal cleaning practices. These findings underline the need for further awareness and the standardization of hygiene protocols to ensure the safe use of RMPs.

Comparatively, studies examining microbial loads in other vaginal products, such as tampons, have shown varying results but emphasize the importance of adhering to stringent hygiene standards during production and use (Briancesco *et al.*, 2018; Veeh *et al.*, 2003). For instance, previous research has highlighted the presence of S. aureus biofilm on tampons, demonstrating the potential for biofilm formation and the importance of using advanced detection methods like fluorescent in situ hybridization (FISH) and PCR to accurately assess microbial presence (Veeh *et al.*, 2003). These insights highlight the need for continued vigilance in monitoring and improving hygiene practices associated with menstrual products to mitigate health risks effectively.

Species of fungi/mould species such as Candida and Aspergillus were implicated in opportunistic infections affecting the female genitals. Species of the *Mucor* genus are filamentous fungi found in the soil, plants, and decaying fruit. Usually, they do not cause diseases as they mostly do not survive temperatures as high as 37^{0}C. The microbial loads of the sample, as obtained by colony count, generally remained lower than the limit set by the FDA throughout the study and can pose little or no health risk to the product users(US Pharmacopoeia, 2016).

The Chi-Square analysis confirmed a significant relationship between cleaning methods and microbial contamination levels ($p < 0.05$ for mesophilic bacteria, molds, anaerobic bacteria, and Staphylococcus spp.). For instance, mesophilic bacterial contamination ($p = 0.009$) was most effectively reduced by the combination of detergent, disinfectant, and ironing, while molds ($p = 0.009$) and anaerobic bacteria ($p = 0.026$) showed similar patterns of reduction. These statistical results validate the critical role of proper cleaning practices in enhancing RMP hygiene and reducing health risks associated with microbial contamination.

The hierarchical clustering illustrated in the dendrogram further enriches the discussion by highlighting the ecological relationships and frequencies of the identified microorganisms. Lactobacillus was the most frequently occurring species (6 occurrences), highlighting its dominance in the microbial community.

In contrast, less frequent species like Clostridium and Veillonella (1 occurrence each) clustered with others such as Bacillus and Fusobacterium nucleatum, suggesting shared environmental niches. The co-occurrence of moderate-frequency species like Candida and Staphylococcus (5 occurrences each) with Pseudomonas aeruginosa (4 occurrences) underscores the potential for synergistic growth under suboptimal cleaning conditions.

The study's findings emphasize the critical need for education on effective RMP cleaning practices, especially in resource-limited settings. Integrating detergent, disinfectant, and ironing into routine cleaning protocols can mitigate microbial risks, promoting the safety and acceptability of RMPs as a sustainable menstrual health solution.

CONCLUSION

This study highlights the microbial contamination risks of reusable menstrual pads (RMPs) subjected to various cleaning methods, identifying diverse bacteria and yeast, including potentially pathogenic species such as Staphylococcus and Pseudomonas aeruginosa. Pads cleaned with water, detergent, or bar soap showed varying levels of microbial contamination, indicating these methods may be insufficient for optimal hygiene. In contrast, washing with detergent and disinfectant, especially when combined with ironing, significantly reduced microbial loads, demonstrating the effectiveness of this approach. These findings provide valuable insights into improving menstrual hygiene and safety, contributing to menstruating individuals' overall health and well-being.

Recommendations

The study recommends combining detergent, disinfectant, and ironing for effective microbial reduction on reusable menstrual pads (RMPs), as this method poses minimal health risks to users. However, sterilization through heat may offer the most reliable control of microbial growth. Future research should assess the long-term viability of bacteria on RMPs, evaluate various disinfectants, and refine ironing parameters to establish best practices for RMP hygiene and user safety.

Future studies should investigate the long-term viability of bacteria on RMPs, explore the efficacy of different disinfectants, and determine the optimal parameters for ironing as a potential additional disinfection step. By establishing best practices for RMP hygiene, we can help ensure the safety and well-being of users.

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Conflict of Interest

There is no conflict of interest in this project.

Author Contributions

AR contributed to the conceptualization, writing - original draft preparation, data analysis, and protocol development. UY contributed to methodology and protocol writing and served as the final reviewer and editor. FT participated in data collection, data analysis, and manuscript writing. SA and AT contributed to protocol development, project administration, and final draft review.

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Sustainable menstrual solutions: a scoping review of novel eco-friendly materials for reusable menstrual pads

Amina Suleiman Rajah[1], **Umar Yunusa**[1], **Faiza Tijjani Tashi**[2], **Sidetu O. Abdullahi**[2], **Abdulaziz Suleiman Tukuntawa**[3]

[1]Department of Nursing Science, Bayero University, Aminu Kano Teaching Hospital, No. 1 Zaria Road Kano, Kano 700233, Nigeria
[2]Department of Nursing, College of Nursing and Midwifery, Gwarzo Road, Adjacent to AKTH, Kano, Kano State 700233, Nigeria
[3]School of Post Basic Nursing, National Orthopaedic Hospital, Kofar Bai, Dala Kano 700252, Nigeria
Address correspondence to Amina Suleiman Rajah, E-mail: asrajah.nsn@buk.edu.ng

ABSTRACT

Background Reusable menstrual pads (RMPs) offer a sustainable alternative, but the effectiveness and properties of novel eco-friendly materials for RMPs remain unclear. The objective of this scoping review is to identify novel eco-friendly materials used for RMPs.

Methods This review adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews. A comprehensive three-step search strategy was employed to locate both published and unpublished studies. Two reviewers independently screened titles and abstracts using the software Covidence. Data were extracted and charted using a standardized form. This search was conducted in February, 2024.

Results The search yielded 479 studies, 37 studies were assessed for full-text review, which led to inclusion of 16 studies. A diverse array of eco-friendly materials were identified for RMPs. The top layer includes bamboo, banana, organic cotton and other natural fibers. The core layer, focused on absorbency, features materials like cotton terry cloth, hemp, bamboo wadding and bamboo kun. The bottom layer uses water-repellent materials, such as polyester, polyurethane laminate, nylon and bio-plastic sheets.

Conclusion This review highlights the potential of plant-based fibers as eco-friendly materials for RMPs.

Keywords menstrual hygiene products, menstruation, reusable menstrual pads, sustainable development, textiles

Introduction

Globally, ~1.8 billion women of reproductive age experience menstruation monthly.[1] Regrettably, ~500 million women and girls lack access to essential menstrual hygiene facilities, including safe and sanitary menstrual management materials.[2] These materials encompass two primary categories: disposable items such as tampons and sanitary pads, and reusable options like cloth pads and menstrual cups. The use of unhygienic materials for menstrual blood collection puts women and girls at risk of infections. Limited literature exists regarding the adoption of reusable menstrual materials in sub-Saharan Africa (SSA), underscoring the need for further research.[2]

Menstrual hygiene management (MHM) remains a significant challenge for women and girls globally, particularly in low- and middle-income countries (LMICs) like those in SSA. Effective, safe, discreet, sustainable and affordable menstrual products are essential for the well-being and empowerment of women and girls. However, many resort to unhygienic alternatives such as newspapers, leaves, cloths and other materials, leading to increased health risks and social stigma.[3] The absence of affordable and effective menstrual products forces many women to use unreliable materials, which can lead to absenteeism from school and work, thereby perpetuating gender inequality.[3]

In addition to the health and social challenges, the environmental impact of disposable menstrual products is significant. Disposable pads and tampons, often composed of plastic and non-biodegradable materials, contribute to vast amounts of waste. An estimated 45 billion menstrual products are disposed of annually, generating over 200 000 tons of waste.[4,5]

Amina Suleiman Rajah, RN, RM, MSC
Umar Yunusa, RN, PHD
Faiza Tijjani Tashi, RN, RM, MSC
Sidetu O. Abdullahi, RN, RM, MSC
Abdulaziz Suleiman Tukuntawa, RN, MSC

This waste often ends up in landfills, water bodies and other natural environments, posing a substantial ecological threat.[3] The production and disposal processes of these products release greenhouse gasses and pollutants, exacerbating environmental degradation.[4]

Therefore, there is a pressing need for sustainable, biodegradable, eco-friendly materials for menstrual products that can address these issues and provide dignified and hygienic solutions. The development and utilization of eco-friendly materials for reusable menstrual pads (RMPs) present a promising alternative. Given the critical need for improved MHM products in LMICs, this scoping review explores the novel eco-friendly materials used in the production of RMPs. The rationale for conducting this scoping review is to address the gap in the literature regarding the full range of menstrual products available and their suitability for use in LMICs. The review will help inform policy decisions, resource allocation and program development aimed at improving MHM in these regions. By focusing on eco-friendly materials, the review also aligns with global sustainability goals and the broader agenda of providing support for MHM in schools and communities.

A scoping review is particularly appropriate for this topic as it allows for a broad examination of the existing evidence on novel materials for RMPs, identifying key concepts, gaps and research priorities. This method provides a comprehensive understanding of the current landscape of MHM products and their potential to improve the lives of women and girls in LMICs. The findings from this review will contribute to the ongoing efforts to enhance menstrual health and hygiene globally, promoting gender equality and empowering women and girls to manage their menstruation with dignity, safety and comfort.

A preliminary search of MEDLINE, the Cochrane Database of Systematic Reviews, Joanna Briggs Institute evidence synthesis and PROSPERO was conducted and no current or underway systematic reviews or scoping reviews on the topic were identified. The objective of this scoping review is to assess the extent of the literature on materials/fabrics used in RMPs.

Review questions

1. What novel eco-friendly materials are adequate for RMPs? (Concept: novel, eco-friendly materials; population: materials for RMPs.)
2. What are the properties of novel eco-friendly materials for RMPs? (Concepts: properties of materials, RMPs; population: novel materials.)
3. What is the reported environmental impact (e.g. biodegradability) of these novel materials compared to conventional materials? (Concepts: environmental impact, biodegradability; population: novel and conventional materials.)

Methods

The protocol for this scoping review was registered in PROSPERO, number CRD42024510383 (https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42024510383). This review adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews.[5] This scoping review aims to explore the landscape of novel eco-friendly materials used for RMPs. A scoping review is ideal for providing a comprehensive overview of existing evidence, elucidating key concepts and identifying research gaps. Unlike systematic reviews, which focus on the quality of studies, scoping reviews aim to offer a broad perspective on the available literature regardless of study quality.[7] Scoping reviews can fulfill several objectives: they can examine the breadth, diversity and nature of the evidence on a given topic; assess the need for a systematic review; synthesize findings from a heterogeneous body of knowledge; and identify gaps in the literature to inform future research. This approach is useful for hypothesis generation and guiding future research efforts.[8]

Search strategy

A three-step search strategy was employed to locate both published and unpublished studies for this scoping review on novel, eco-friendly materials used in RMPs. An initial limited search was conducted across several key electronic databases, including PubMed, MEDLINE, Cochrane library, Scopus, AJOL, Google Scholar, Web of Science, Worldwide science, Science.gov and Global Health database. This initial exploration aimed to identify relevant keywords and index terms used in existing literature.

The keywords and index terms gleaned from the initial search informed the development of a comprehensive search strategy tailored to each database. This strategy combined controlled vocabulary (like MeSH terms in PubMed) with keywords related to the target population, concepts and interventions. Boolean operators (AND, OR, NOT) were strategically used to refine the search results and ensure they captured relevant studies.

The search was not limited to electronic databases alone. The reference lists of all included studies were meticulously screened to identify additional relevant articles. Furthermore, the review explored gray literature sources such as conference proceedings, theses, dissertations and relevant websites (e.g. manufacturer websites, NGO reports) to potentially uncover unpublished studies. The search focused on articles written in English language.

The key search terms used for PUBMED database are ('women' OR 'girls' OR 'mens*') AND ('eco-friendly materials' OR 'plant based fibers' OR 'novel materials' OR 'cloth' OR 'towel' OR 'product' OR 'absorbent' OR 'Sanitary') AND ('reusable menstrual pads' OR 'recyclable menstrual pad' OR 'sustainable menstrual pad' OR 'disposable menstrual pads' OR 'menstrual pads').

Study screening and data charting

The study screening and data charting processes were conducted systematically to ensure a comprehensive and unbiased selection of relevant studies. The initial search strategy generated a list of items that were screened for duplicates. After removing duplicates, the remaining items were subjected to a detailed screening process based on their titles and abstracts. Two researchers (AR and FT) independently screened the titles and abstracts of the articles using the Covidence software, version 2024. Articles that clearly did not meet the inclusion criteria were excluded at this stage. In cases where there was uncertainty about an article's eligibility, it was advanced to the full-text review stage for further evaluation.

Full-text articles were then reviewed to determine their eligibility based on predefined criteria, including the focus on novel eco-friendly materials for RMPs and their properties and environmental impact. Additionally, other methods, such as citation searching and screening of relevant websites and organizational reports, were employed to identify additional studies. Data from the included studies were extracted and charted using a standardized form to ensure consistency and comprehensiveness in capturing relevant information.

A data-charting form was developed to document author(s), study country, year of study, study design, study purpose and key findings related to the article's objectives. A quality assessment was carried out using the Johns Hopkins Nursing Evidence-Based Practice Rating Scale.[7] Quality ratings include a Roman numeral to assign a level of evidence and a letter to indicate the quality as high (A), good (B) or low (C).

Data items

The main focus is on the material type (e.g. bamboo fiber) and its properties (absorbency, comfort) compared to conventional materials. Environmental impact, including biodegradability, was also assessed. Finally, the review looked for any available data on user experience and acceptability of these new materials.

Eligibility criteria

The following are the criteria used to select the studies to be included in the review:

i. Studies that investigate novel eco-friendly materials used for RMPs.
ii. Research articles published in the English language.
iii. Studies that compare eco-friendly materials with conventional disposable menstrual pads.
iv. Articles reporting on the properties and environmental impact of novel eco-friendly materials used for RMPs.
v. Any study with information on use, safety, effectiveness, efficacy, cost effectiveness, environmental impact, adoption or acceptability of RMPs (cohorts, trials or cross-sectional studies; qualitative, quantitative or mixed method studies).

Results

The researchers generated the initial 431 items. After removing duplicates, 429 items were screened by title and abstract by two researchers (AR, FT) independently, excluding 363 articles using the software Covidence, version 2024. Thirty studies were sought for retrieval, one was unable to be accessed. Twenty-nine studies were assessed for eligibility and 17 studies were excluded based on wrong outcomes ($n = 2$), wrong intervention ($n = 6$) and wrong study design ($n = 9$).

Forty-eight additional studies were identified through other methods including websites ($n = 15$), organizations ($n = 3$) and citation searching ($n = 30$). Twelve reports were sought for retrieval, eight were assessed for eligibility and finally, four were included in the review (Fig. 1). Sixteen studies were included in the final synthesis. Data charting is summarized in Table 1.

All 16 studies focused on identifying different materials/fabrics used for RMPs. Six studies were experimental researches, one was quantitative descriptive, seven were review articles and two were mixed method researches. This paucity of evidence clearly demonstrates a need for research on novel materials for RMPs.

Quality appraisal

A quality assessment was carried out using the Johns Hopkins Nursing Evidence-Based Practice Rating Scale.[7] Eight articles in this scoping review were Level I evidence [experimental study, randomized controlled trials (RCT) or mixed methods design that includes only a Level I study] and quality A (high quality), meaning the research was consistent with generalizable results; sufficient sample size for the study design; adequate control; definitive conclusions; consistent

Table 1 Characteristics of included studies

S/N	Author	Reference country	Year of study	Study design	Study purpose	Key findings	Level of evidence
1	Tiku	Ethiopia	2020	Experimental	To design and develop a feminine reusable pad without a pad holder for economically challenged people around Ethiopian rural area.	100% knitted cotton fabric at the top, polywadding at the middle and at the bottom with water repellent materials like polyester/nylon plain weave fabric.	Level I A
2	Kobia, Lumutenga and Khatsa	Uganda	2022	Mixed method	To produce an improved, cost-effective reusable sanitary pad (HERS pad) using the Human Centered Design (HCD) model.	Topper fabric: flannel made out of cotton Core fabric: fleece made from cotton Waterproof fabric: a variant PUL fabric Backing fabric: flannel, same as the topper fabric	Level I A
3	Ganguly, Sirpati and Nath	India	2022	Review	To identify women's concerns about menstruation products and effective menstrual management alternatives.	Bamboo Fiber, banana fiber and water hyacinth.	Level V A
4	Tiku	Ethiopia	2022	Mixed method	To design and develop a feminine re-usable maxi pads for economically challenged people	100% bleached knitted cotton, which is used as a top layer, poly wadding (non-woven) used at the middle layer and PUL water resistance fabric is used as lower layer	Level I A
5	Foster and Montgomery	Low and middle income countries	2021	Experimental	Low-cost biodegradable absorbents (cotton terry cloth, linen, hemp cloth and bamboo wadding) were investigated in gelatine solution in terms of their absorptivity for use in menstrual hygiene.	Bamboo wadding exhibits the highest absorptivity index (7.86), greater than cotton terry cloth (0.84), hemp cloth (1.4), linen (1.57) and a commercial sanitary pad (4.38)	Level I A
6	Srikavi and Mekala	China	2021	Review	Development of ecologically sustainable sanitary napkins for the green economy.	Plant fibers such as jute, bamboo, bananas, water hyacinth, flax fibers and kenaf as an alternative raw material in the manufacture of sanitary napkins.	Level V A

(Continued)

Table 1 Continued

S/N	*Author*	*Reference country*	*Year of study*	*Study design*	*Study purpose*	*Key findings*	*Level of evidence*
7	Foster and Montgomery	Low and middle income countries	2021	Experimental	To analyze the absorption capacity of readily available, natural biodegradable materials for the purpose of feminine sanitary hygiene products in LMICs.	Bamboo fiber in a non-woven wadding form was 9-fold more absorbent than cotton and almost twice as absorbent as a standard sanitary pad. Bamboo also reduces odor as the fiber is filled with multiple micro-holes and micro-gaps.	Level I A
8	Kavinkumar *et al.*	India	2023	Review	To study sanitary napkin, including its composition, structure, and use-related disorders and negative effects.	Cotton fibers, cotton terry cloth. Hemp is a good absorbent material and has antimicrobial qualities. A special bio-agent known as 'Bamboo Kun' that inhibits bacteria growth and is antibacterial has also been discovered in bamboo. Banana fiber is a natural superabsorbent and particularly effective at securing menstruation fluid polyethylene and polypropylene were used for the bottom and top levels, respectively. In order to make the outer barrier and absorbent core of sanitary napkins extremely absorbent, jute fiber, an organic and sustainable fiber, has also gained popularity.	Level V A
9	Mekala	India	2021	Experimental	Development of eco-friendly sanitary napkins using *S. trifasciata* fibers coated with *Rosa damascena* extracts.	Microencapsulation of *S. trifasciata* fibers with *Rosa damascene* possess antimicrobial properties against different microorganisms, such as *E. coli*, *Pseudomonas* sp. and *Candida* sp. Thus *S. trifasciata* plant fibers could be an ideal substitute for absorbent core used in sanitary pads.	Level I A

(*Continued*)

Table 1 Continued

S/N	Author	Reference country	Year of study	Study design	Study purpose	Key findings	Level of evidence
10	Jeyakanthan, Schuster and Shaik	Germany	2023	Experimental	Development of ecological absorbent core sanitary pads in combination of kenaf and chitosan fibers.	Nonwoven bamboo will be used as the top layer, nonwoven cotton will be used as the second layer, the absorbent core is to be made by the combination of kenaf and chitosan fibers as the third layer, cotton as the fourth layer and cornstarch-based bioplastic sheets as the bottom layer.	Level I A
11	Barman, Katkar and Asagekar	India	2017	Review	To identify natural and sustainable raw materials for sanitary napkin.	Top sheet—organic cotton, TENCEL®Biosoft, which is a lyocell fiber. Absorbent core—bamboo fiber, jute fiber, banana fiber and flax. Barrier—sheet polyethylene and polyurethane (non-biodegradable). PLA fiber, which is derived from cornstarch.	Level V A
12	Patil et al.	India	2023	Review	Investigates the incorporation of natural fibers into composite materials and their impact on various industries.	banana fibers, papaya fibers, jute fibers, cotton, flax (linen) and wool.	Level V B
13	Achuthan et al.	India	2021	Quantitative	To study the feasibility and acceptability of a novel banana fiber based menstrual pad amongst women living in rural and urban environments.	Banana fibers	Level III A
14	Shibly et al.	Bangladesh	2021	Experimental	To create a sanitized and biodegradable pad in order to replace SAP with environmentally sound biopolymer that give rural poor women competent performance and characteristics.	Cotton, viscose, wood pulp, sodium alginate and carboxymethyl cellulose.	Level I A

(Continued)

Table 1 Continued

S/N	Author	Reference country	Year of study	Study design	Study purpose	Key findings	Level of evidence
15.	Shanmuga, Safrin and Baranitharan	India	2022	Review	To identify eco-friendly menstrual absorbents fibers.	Cotton fiber, bamboo fiber, banana fiber, pina fiber from pineapple leaf, hemp fiber.	Level V II
16.	Hand et al.	USA	2023	Review	To explore and synthesize the current frugal methods to develop menstrual hygiene products with plant materials that are inexpensive, environmentally friendly and easily accessible compared to plastic-based, commercial pads.	water hyacinth, bamboo, banana stems, papyrus, cotton and hemp.	Level V A

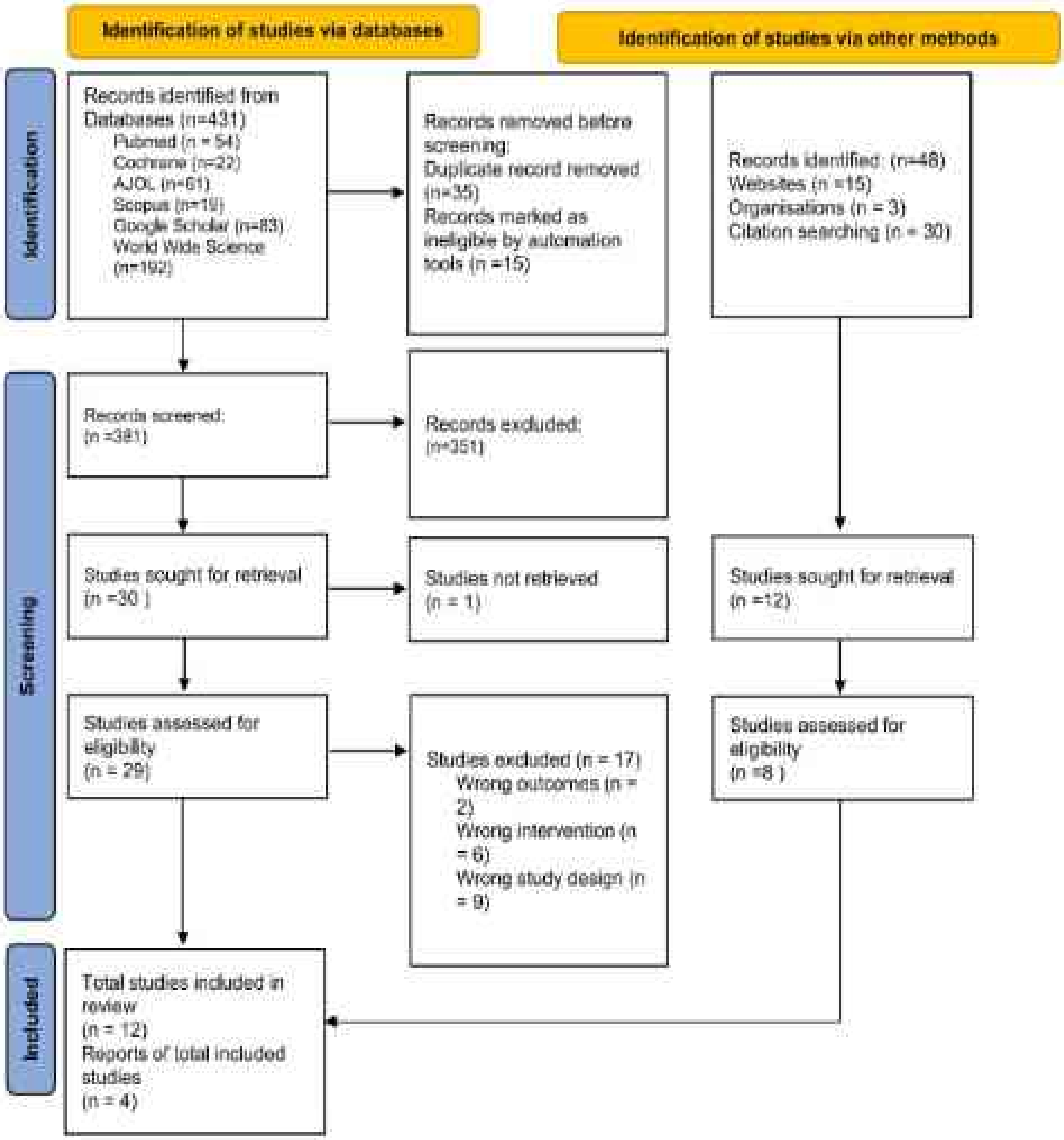

Fig. 1 Prisma flow chart.

recommendations based on comprehensive literature review that includes thorough reference to scientific evidence. Seven articles were Level V and of high or good quality, while one article was Level III evidence of high quality. Although the majority of literature was of good quality, some of the level of evidence on novel materials for reusable menstrual pad was limited to literature reviews; there were no RCTs and therefore no meta-analyses.

Novel eco-friendly materials for RMPs

This scoping review explored a diverse array of novel, eco-friendly materials used in RMPs. These materials offer a more sustainable alternative to traditional disposable pads, which often contain harmful chemicals and contribute to landfill waste. These materials are strategically categorized into three distinct layers—top layer, core and bottom layer—to accommodate the tri-partite layering system integral to the design of RMPs.

The top layer is directly in contact with the skin and needs to be soft, comfortable and breathable. The materials used for the top layer include bamboo fiber,[8–12] banana fiber [8,9,11–15], organic cotton fibers,[8,11,13,14,16–18] cotton flannel,[19] jute,[9,13,14] non-woven bamboo,[18] bamboo pulp,[8] water hyacinth,[8,9,12] 100% knitted cotton fabric,[20,21] flax fibers,[9] kenaf,[9] TENCEL® Biosoft (lyocell fiber),[17] papaya fibers[14] and papyrus.[12]

The core serves as the primary absorbent layer, utilizes materials known for their high absorbency and durability, such as cotton terry cloth,[13,22] linen,[22] hemp cloth,[11–13,22] bamboo wadding,[22] cotton fleece,[19] poly-wadding,[20] bamboo kun,[13] jute,[13,14,17] *Sansevieria trifasciata* plant fibers,[23] kenaf and chitosan fibers,[16] bamboo fiber,[17] banana fiber,[17] flax[17] and wool.[14]

The bottom layer is comprised of water-repellent materials like polyester/nylon plain weave fabric,[20] polyurethane laminate (PUL),[17,19,20] polyethylene,[13,16,17] polypropylene,[13] corn starch-based bio-plastic sheets[16] and poly lactic acid (PLA) fiber, which is derived from corn starch.[17]

Properties and environmental impact of novel eco-friendly materials

The scoping review revealed several key properties of novel eco-friendly materials used in RMPs, highlighting their absorptive, antimicrobial and structural advantages.

Bamboo

Bamboo wadding exhibits an exceptionally high absorptivity index of 7.86, significantly outperforming other materials, such as cotton terry cloth (0.84), hemp cloth (1.4), linen (1.57) and even commercial sanitary pads (4.38).[22] Bamboo fiber is nine times more absorbent than cotton and nearly twice as absorbent as a standard sanitary pad.[10] The material's structure, filled with multiple micro-holes and micro-gaps, not only enhances absorbency but also aids in reducing odor.[9,10] Bamboo fibers are biodegradable, elastic, environmentally friendly, antifungal, bacteriostatic, antibacterial, hygroscopic, hypoallergenic and natural deodorizers.[9] Bamboo fibers are effective against bacteria, such as E.coli, *Staphylococcus aureus* and Bacillus sp., as well as fungi, such as *Candida albicans*.[9]

A unique bio-agent known as 'Bamboo Kun' has been discovered within bamboo fibers. This agent inhibits bacterial growth, imparting antibacterial properties to bamboo-based materials, thereby enhancing their suitability for sanitary products.[13] It has a natural antibacterial, antifungal and antistatic qualities.[9]

Hemp cloth

Hemp fiber is a biodegradable, eco-friendly, moisture permeable, anti-static, insulation, warmth retention, anti-UV, anti-mildew and antibacterial.[9] It was found out that hemp fiber showed activity against *Escherichia coli*, *S. aureus* and *C. albicans*.[9]

Banana fiber

This is a biodegradable agro waste that is reusable, monocarpic, replantable and contains natural qualities, such as UV protection, moisture absorption and anti-oxidant properties.[9] Banana pads are completely biodegradable and decompose completely within one year.[9] The amount of CO2 emitted from one disposable sanitary pad is ~0.041 kg CO2, while the amount of CO2 liberated from banana fiber is estimated to be <0.01 kg CO2.[9,14]

Polyethylene and polypropylene

Polyethylene and polypropylene are used for the bottom and top layers of RMPs, respectively. These materials provide necessary waterproofing and structural integrity, ensuring the pads are leak-proof and durable.[13]

Jute fiber

Jute fiber is recyclable, 100% biodegradable and environmentally friendly.[9] It is extremely absorbent,[13] causes no skin irritation, have antistatic properties, insulating properties and moisture regain of ~13.75%.[9] Jute fiber can absorb up to 23% of water under high humidity and contains 61–71% cellulose, 14–20% hemicelluloses and 12–13% lignin.[9]

S. trifasciata fibers

The fibers of *S. trifasciata*, when microencapsulated with Rosa damascena, possess potent antimicrobial properties. They are effective against various microorganisms, including *E. coli*, Pseudomonas sp. and Candida sp. This adds an extra layer of protection and hygiene to menstrual products.[23]

Kenaf fiber

They are bio-degradable, environmentally friendly and predominantly made up of cellulose (45–57%), hemicelluloses (21.5%), lignin (8–13%) and pectin (3–5%).[9]

These findings are particularly relevant to manufacturers, healthcare professionals and environmental advocates. The use of these materials can help create sustainable menstrual products, reduce environmental impact and provide safer, more comfortable options for users.

Additionally, researchers are encouraged to conduct further studies, particularly RCTs, to evaluate the long-term performance and potential health benefits of these materials in RMPs. Finally, research on the cost-effectiveness, long-term durability and life cycle assessment of these materials is crucial for a comprehensive understanding of their overall impact.

Discussion

The findings from this scoping review provide a comprehensive overview of various eco-friendly materials identified for RMPs and their potential to replace conventional disposable pads. These materials, including bamboo, banana, organic cotton fibers and others, offer significant environmental benefits compared to traditional disposable pads, which are largely composed of non-biodegradable materials and contribute to substantial environmental pollution.

Previous studies have highlighted the environmental hazards posed by disposable menstrual products. For instance, Yadav[5] noted that conventional disposable pads, which contain plastic and other non-biodegradable components, can take up to 500–800 years to decompose, leading to massive waste management challenges and environmental contamination.[5] Olatunile and Ajayi discussed the improper disposal of menstrual waste in Nigeria, emphasizing the pressing need for sustainable alternatives to mitigate environmental and public health risks.[4]

The materials identified in this review exhibit several eco-friendly properties. For instance, bamboo and banana fibers are not only biodegradable but also possess antimicrobial properties, which can enhance the hygiene and safety of menstrual products.[7] The core layers of reusable pads made from materials like hemp, cotton terry cloth and bamboo lon demonstrate superior absorbency and durability, which are critical for effective menstrual management.[9,10,22] These materials also reduce the reliance on synthetic fibers, thereby decreasing the carbon footprint associated with their production and disposal.[5]

Comparing these findings with previous research, emphasized the growing acceptance and benefits of reusable menstrual products in Ghana, highlighting their potential to improve menstrual hygiene and reduce environmental impact.[1] Van Eijk *et al.* further underscored the global shift toward reusable menstrual products, noting their positive impact on menstrual health management and environmental sustainability.[3]

Conclusion

This scoping review has highlighted a gamut of novel, eco-friendly materials used in RMPs, categorized into top, core, and bottom layers to maximize comfort, absorbency and water repellence. These materials, including bamboo, hemp, banana fiber, organic cotton and others, offer significant advantages over traditional disposable pads by reducing environmental impact and enhancing user experience through superior absorbency and antimicrobial properties.

However, the findings also reveal gaps in high-quality evidence, particularly regarding user experiences and comprehensive life cycle assessments of these eco-friendly materials. While the identified materials show promise, further research is necessary to validate their efficacy, safety and acceptability across diverse populations. Systematic reviews and randomized controlled trials are recommended to provide robust evidence on the performance and sustainability of these materials.

Strengths and limitations

One of the primary strengths of this scoping review is its pioneering nature; it is the first study to comprehensively examine and categorize the novel, eco-friendly materials used in RMPs. By systematically identifying and synthesizing existing research, this review provides a valuable foundation for future investigations in this relatively unexplored area. The review's detailed classification of materials based on their specific functions within the tri-layered structure of reusable pads offers critical insights for both researchers and manufacturers aiming to develop more sustainable and effective menstrual hygiene products.

The scoping review process has several limitations. Firstly, the review was constrained by the quality and scope of the available literature, with a notable paucity of high-level evidence, such as RCTs and meta-analyses. The reliance on various study designs, including experimental, descriptive and review articles, introduces heterogeneity that can affect the robustness of the conclusions.

Supplementary data

Supplementary data are available at the *Journal of Public Health* online.

Conflict of interest

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this article. LA, PD, FD, MAD, JLSG, and PJ received consulting fees from Sanofi Pasteur MSD. PP performed medical writing services on behalf of Sanofi Pasteur MSD.

Authors' contributions

AR contributed to the conceptualization, writing—original draft preparation, protocol development, search strategy execution, data screening and charting. UY contributed to methodology and protocol writing and also served as the final reviewer and editor. FT participated in data screening and charting and manuscript writing. SA and AT contributed to protocol development, project administration and final draft review.

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Data availability

The data supporting the findings of this study are available within the article. Any additional data that support the study's findings are available from the corresponding author upon request.

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