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

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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:

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

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.

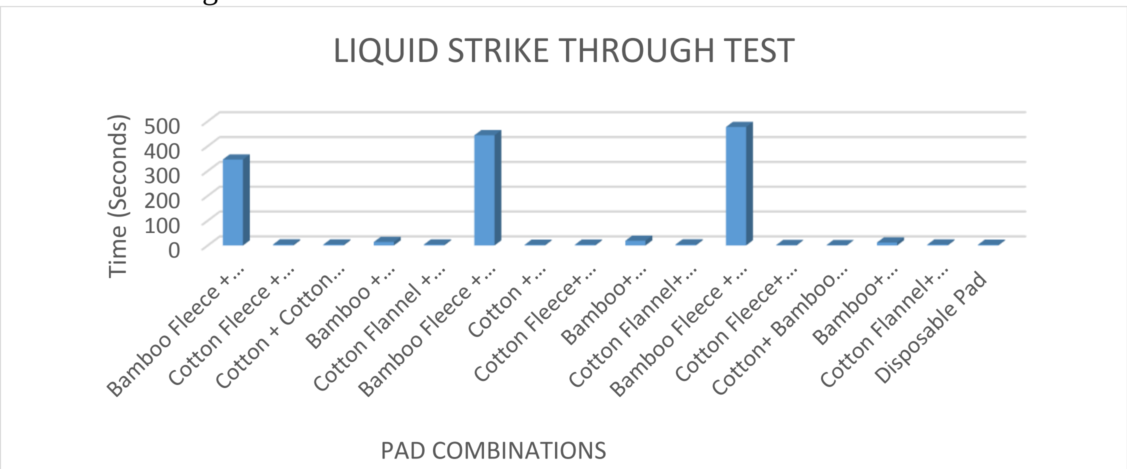

Figure 5: Liquid Strike through Test

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.

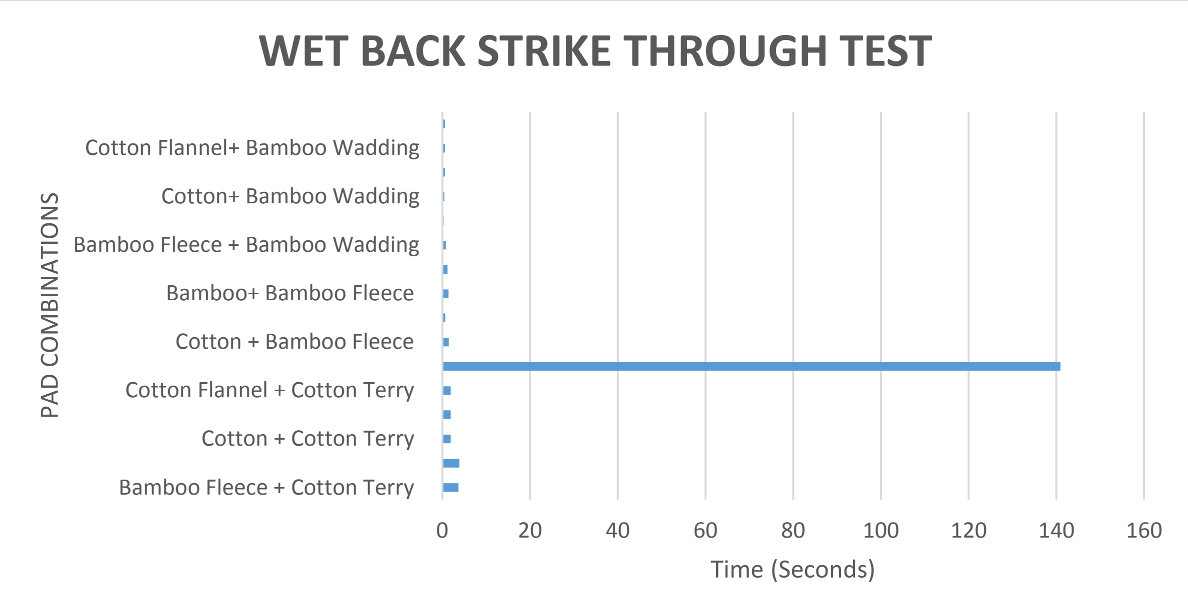

Figure 6: Wet Back Strike Through Test

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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