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# Development of biopolymer-based menstrual pad and quality analysis against commercial merchandise

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## Abstract

**Background:** Managing menstrual hygiene in the least developed countries represents a significant obstacle for women and girls. Commonly dirty stuffs are used to control the menstrual cycle which causes many diseases, while disposable hygiene-absorbent material during menstruation is an essential requirement. Most local commercial sanitary napkins offer high absorptiveness and flexibility; however, most of them, due to the use of synthetic superabsorbent polymer (SAP) within the core layer, are not biodegradable and harmful to human skin. This research aims 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.

**Result:** For the construction of the model, some of the current sanitary pads from the local market are examined. Six models are designed using various biopolymers such as cotton, viscose, wood pulp, sodium alginate and carboxy methyl cellulose (CMC) in different proportions as the core absorbent layer to boost requirements such as absorption, fluid retention strength, coziness and cost reduction. The sanitized pads have gone through various investigations such as antimicrobial activity, wicking ability and water retention capacity to standardize vital features and value. The experimental results show the use of sodium alginate and CMC is a possible replacement for SAP as the best comparable result is observed in template consuming sodium alginate, CMC and cellulosic fibre. Non-woven fabric treated with neem extract forming the outer layer of sanitary napkin serving with antimicrobial activity of more than 90% against both gram-positive and gram-negative bacteria.

**Conclusion:** Outcomes recommend significant advancement and cost-effectiveness of the newly designed archetype. Sanitary napkins without SAP can be a safe disposal solution and can therefore have a sustainable environmental impact.

**Keywords:** Feminine sanitary napkins, Superabsorbent polymers, Sodium alginate, Carboxymethyl cellulose, Biopolymer, Antimicrobial activity, Biodegradability

## Background

Menstruation is a natural feminine function that occurs every 21–28 days with a duration of five days in a menstrual cycle (Woeller and Hochwalt 2015) and plays a

significant role in the reproductive system for women (Crofts 2012). Women typically experience a menstrual period between ages of 11 and 50 years, and regular menstrual periods are usually 3–7 days, with a menstrual average blood loss of 35 millilitre (ml) where the blood loss (10–80) ml is considered normal (Nyoni et al. 2014). In particular, at the start of the early menstrual day the rate stays high, but the flow rate is declining slowly from the second day of the cycle to the last few days (Nyoni

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et al. 2014). Menstrual fluid consists of approximately 50–60% of blood with mixtures of uterine, cervical and vaginal secretion and mucous materials (Fraizer 2006; Chakwana and Nkiwane 2014).

In the developing world, women in all societies (i.e. upper, middle and lower classes) are not sufficiently aware of menstrual hygiene management, resulting school absenteeism, infections and various diseases to women's health, embarrassment and barriers to work in women that cause low productivity (Bharadwaj and Patkar 2004). In order to collect and retain menstrual fluids, poor and unconscious women generally use dirty cloths, rags that are unhygienic for their health. Moreover, poor women are not used to wearing underwear as a consequence of which they are not interested in using commercial sanitary napkins although panty or other underwear is essential to use commercial sanitary napkin. Because of lack of awareness, product costs and their socio-economic structure, the scenario requires designing such a form of hygienic sanitary napkin that can be generated at very low expense and environmentally friendly.

The health-conscious female is nowadays following a multitude of products including sanitary pads, tampons, panty liners and menstrual cloth pad with three principal layers: the top sheet, the absorbing core of absorbing materials and the leaking barrier sheet (Yadav et al. 2016). Traditionally, the absorbent core has been developed from wood pulp but continuous efforts are being made to substitute it with air-laid wood pulp and SAP to increase its efficiency of absorption (Zohuriaan-Mehr et al. 2010). Super absorbent polymers, such as sodium polyacrylates, are integrated into the absorbent core along with soft cellulose fibre to enhance the absorbency. The loosely cross-linked structure along with extended polymer chains with water enables them to attain additional absorbency. Despite this specific benefit, the commercial sample has some constraints, since SAP are petroleum-based polymers that do not easily deteriorate in earth (Yadav et al. 2016). SAP also causes some adverse effects on the health of the user as long-term exposure causes severe reactions such as skin infections and even toxic shock syndrome (Berkley 1987). Since this polymer remains inert and is not readily decomposed by bacteria, it pollutes the atmosphere enormously (Hubble et al. 2013). In addition, a woman disposes an enormous number of pads in her lifetime that are available as non-biodegradable and cannot be reused. Hence, landfills are eventually loaded with non-disposable pads used by the entire woman in the globe that is so alarming to our environment.

Arunachalam Muruganatham recently developed low-cost Indian sanitary napkin where he has tried to reduce the amount of SAP utilization in the core layer

of the pad but still did not offer biodegradability. Several private NGOs have developed low-cost sanitary napkin by using cotton fibre in the core layer in large amounts, which certainly makes the sanitary napkin a little heavier and thicker than the commercial pad weight and eventually leads to consumer discomfort. The performance of locally developed sanitary napkin is poor, as a result of their poor retention capacity, and a single pad is not sufficient for menstrual fluid collection for an entire long day. Besides, synthetic material in commercial merchandise usually blocks moisture and temperature, leading to yeast and bacterial growth in the vagina which cause toxic shock syndrome and plasticizers used to achieve smooth finish can lead to multiple organ failure (Berkley 1987). Appropriate antimicrobial treatment other than standard sterilization is therefore required to promote product hygiene status.

The consequential advantage of the selection of sodium alginate and cellulose-based hydrogels for the development of sanitary napkins over SAP lies in their biodegradability and environmentally friendly nature. Sodium alginate is an acidic polysaccharide composed of linear block copolymer 1–4 bound  $\beta$ -D-mannuronic acid and  $\alpha$ -L-guluronic acid (Bardajee et al. 2008). On the other hand, CMC comprises hydrophilic carboxylate units in its polymeric structure that can consume lots of water. The higher number of negative ( $\text{COO}^-$ ) charges of CMC in gels eventually enlarge the molecular chains of repulsion, leading to an increase in mesh size and assistance in the uptake of water (Tang et al. 2014). Several scientists have earlier documented on the biodegradability and biocompatibility of sodium alginate and CMC and it is a common perception that these biopolymers are beneficial to the environment and to personal health (Hubble et al. 2013). Eventually, natural and convenient antimicrobial agent, i.e. neem extract, is used to treat non-woven fabrics which construct the established prototype's top layer and pocket fabric to induce user skin security.

### Objective

The choice of biopolymers in the absorbent core of sanitary napkin could therefore incorporate the biocompatibility, biodegradability and non-toxicity of these products which is the key objectives of this research.

### Material and methods

100% cotton, viscose fibre and tissue paper used as the core material in the experimental study were obtained from Square Textile Mills Ltd., Bangladesh. Finished non-woven fabric (90% polyester + 10% polypropylene) was purchased from the local market to be incorporated into the upper and lower napkin layers. As a substitute for SAP, commercial grade sodium alginate

and CMC were purchased from Dysin Bangladesh and used to develop sanitary pad samples without modification. During the use of neem extract on non-woven fabric, analytical grade citric acid from Merck, India, was used as binder. Whatman No. 1 filter paper was used for neem extraction obtained from the Department of Textile Engineering, Primeasia University, Bangladesh. Measurement of wicking height was taken using a direct dye solution collected from Dysin Bangladesh. 0.9% saline solution and distilled water were collected from Incepta pharmaceuticals ltd, Bangladesh. The neem-treated non-woven's antimicrobial efficacy has been examined against *Staphylococcus aureus* (gram positive) and *Escherichia coli* (gram negative) collected from the Department of Microbiology, Primeasia University, Bangladesh. Three feminine commercial products (CS 01 to CS 03) were bought from the local market as a reference, namely Whisper Ultra Clean, Freedom (Regular) and Joya (Regular).



**Fig. 1** Developed sanitary napkin

### Sample preparation

In this research, finished non-woven fabrics were first treated with neem extract solution, collected from freshly neem leaves that grown in Bangladesh National Botanical Garden. Fresh neem leaves were washed with distilled water and cut into fine pieces, then boiled with 100 ml of distilled water, and filtration was performed using whatman No. 1 filter paper. For further investigation, three different concentrated neem extracts (10%, 25% and 50%) were prepared and used. The grafting of the neem leaf extract substrate was incorporated by the pad-dry-cure method. The non-woven fabric was immersed in a solution comprising neem leaf extract (10%, 25% and 50%) in three distinct conical flasks. The citric acid binder (1%) was then introduced to all three flasks and held for 40 s (Patel and Desai 2014). Excess solution has been separated from the test fabric by using Copower Technology Ltd, Taiwan's Laboratory Padding Mangle at room temperature, at a pressure of 2 kg/cm<sup>2</sup>. After padding, all the test samples were dried at 80 °C for 20 min and then cured at 120 °C for 5 min (Fig. 1).

The pad samples, developed from treated non-woven fabric, consists of three layers where the first layer is porous non-woven (285 mm × 75 mm), the second layer is non-woven pocket (220 mm × 70 mm) containing cellulosic polymers, sodium alginate, CMC of different proportions and the third layer is polyethylene (285 mm × 75 mm). Newly engineered core forming machine (Fig. 2) transformed the core forming materials into cake form and inserted into the pocket for quick absorption of menstrual fluid. All layers were sealed together by heat sealing machine (Model PS-1000,



**Fig. 2** Core forming machine fabricated for this study

Impulse Heat Sealer, china). The UV-treated sterilizer (Model YTP280MT1, UV, china) sterilizes all developed pad samples. Newly developed sample (Fig. 1) is categorized into six samples (DS-01 to DS-06) based on different core forming materials and they were coded as shown in Table 1.

#### Antibacterial property of non-woven fabrics

ASTM E2149-01, a quantitative antimicrobial test method intended to assess the resistance of non-leaching antimicrobial processed samples to microbe development under dynamic contact conditions, has been used to investigate the antimicrobial characteristics of neem extract-treated non-woven fabrics (Ferrero and Periolatto 2012). Antimicrobial efficacy was investigated against *S. aureus* (gram positive) and *E. coli* (gram negative). Each culture was suspended in a small amount of nutrient broth, spread on the nutrient blood agar plate and incubated at 37 °C for 2 h. Two single colonies were collected with an inoculating loop from the agar plate, suspended in 5 ml of nutrient broth and incubated at 37 °C for 18 h. The final concentration of  $1.5\text{--}3.0 \times 10^5$  colony forming units per millilitre (CFU/ml) was produced by diluting each culture with a sterile buffer solution (0.3 mM phosphate buffer, p<sup>H</sup> 7.2) which was used as a diluent in all tests. These dilute culture solutions have been used for the antimicrobial experiment.

A 250-ml flask comprising 50 ml of active bacterial dilution ( $1.5\text{--}3 \times 10^5$  CFU/ml) has been provided for each neem-treated and one untreated sample, and small pieces (1 cm × 1cm) of non-woven fabric samples were put on flask. All flasks were loosely capped, positioned on a shaking incubator, shaken at 37 °C and shaken at 120 rpm for 1 h. Using the buffer solution, a series of dilutions were produced and each 0.1 ml of dilution was put in the nutrient agar plate. The inoculated plates were incubated at 37 °C in the incubator (USA Binder) for 18–24 h, and the surviving cells were counted. The safety

cabinet (Clernair from Belgium) was used for the preparation of bacterial culture and transfer to agar plate. The antimicrobial activity was demonstrated as a percentage reduction of the organism after contact with the test specimen compared to the number of bacterial cells that survive after contact with the control using Eq. 1 (Arif et al. 2015).

$$\% \text{ Reduction} = \frac{B - A}{B} \times 100 \quad (1)$$

where A and B are the surviving cells (CFU/ml) for the flasks containing test samples (neem-treated non-woven fabric samples) and the control (blank non-woven fabrics) respectively after 1-h contact time.

#### Evaluation of developed sanitary napkin

##### Absorbent capacity test

An absorbent capacity test is used to assess a material's ability to absorb a liquid and how quickly it does this, defined as its speed of absorption (ISO/IEC 17025). It is being used by companies that produce products such as sanitary napkin, baby diapers, wipes, paper towels, sponges and personal and feminine hygiene items. The specimen will be measured before and after the shower in this experiment. Dry napkin weight is first taken and then soaked in a 200 ml 0.9% saline solution and hangs for 1 min to allow the saline solution to drain from the napkin and the moist napkin's weight has been taken. (Fraizer 2006; EDANA 2018). For evaluating absorbent capacity of developed sanitary napkin, saline solution (0.9 wt% NaCl) was used as a substitute of blood (Yadav et al. 2016).

##### Rewet/wet back test

The rewet or wet back of sanitary napkin was assessed in accordance with ISO/IEC 17025 where 5 ml 0.9% saline solution is poured into the centre of napkin and wait for 1 min. After that 3 g dry filter paper is put on centre for

**Table 1 Test pad samples coding**

Test pad samples	Code
Commercial sample-01 (Whisper Ultra Clean)	CS-01
Commercial sample-02 (Freedom, Regular)	CS-02
Commercial sample-03 (Joya, Regular)	CS-03
Developed sample-01(100% cotton)	DS-01
Developed sample-02 (50% cotton + 50% viscose)	DS-02
Developed sample-03 (33.3% cotton + 33.3% viscose + 33.3% tissue paper)	DS-03
Developed sample-04 (50% cotton + 50% viscose + 1 gm sodium alginate)	DS-04
Developed sample-05 (50% cotton + 50% viscose + 1 gm CMC is added)	DS-05
Developed sample-06 (50% cotton + 50% viscose + 1 gm CMC + 1gm sodium alginate)	DS-06

15 s which give first filter paper weight and repetition of the procedure will give second filter paper weight. The difference between second and first filter paper weight was recorded for all sample, and all the procedures were performed in standard testing atmosphere (Temperature  $20 \pm 2$  °C and relative humidity  $65 \pm 2\%$ ) (EDANA 2018).

#### Strike through test

The experiment was established to assess the rate of penetration of a single drop of liquid through the sanitary pad samples using only a small volume (5 ml) of 0.9% saline solution (ISO/IEC 17025). In order to execute this experiment, a drop of the test liquid was permitted to fall on the pad sample and the penetration rate of the liquid was thoroughly observed. The pad was assessed by measuring the time taken for the blood substitute to be absorbed from the upper layer of the pad to the inner layer. The drop was monitored closely until the drop of the test liquid appeared on the pad sample like a dull spot, the pad being observed over the same period of time (EDANA 2018).

#### Retention capacity test

After soaking 5 min in 200 ml 0.9% saline solution, both commercial and developed sanitary napkins were removed from the liquor and the wet napkins were centrifuged for 30 s and then eventually assessed the retention ability in accordance with ISO/IEC 17025 (EDANA 2018).

#### Wicking height test

The column (vertical wicking) experiment has been used to evaluate the distribution of absorption of the multiple samples, preceded by the AATCC TM 197-2011 norm. This test method is used to evaluate the ability of vertically aligned pad specimens to transport liquid along and/or through them, by capillary action and also applicable to woven, knitted or non-woven fabrics. A pad sample of (5 cm × 18 cm) is taken in case of the wicking test and a mark is created at 1 cm from the bottom. Then 1 cm portion is immersed in 1 per cent direct dye solution for 5 min and then the distance travelled above 1 cm mark by the coloured solution is expressed in mm.

#### Physical testing of sanitary napkin

Sanitary napkin's general physical attributes are the thickness, length, width and weight which are assessed according to (ISO/IEC 17025). Based on the commercial sanitary napkin standard, the length, width and weight of the developed sanitary napkin are taken into account and evaluated (Fraizer 2006; EDANA 2018). Ana thickness tester (Model MAG-C1001, India, MAG Ana Thick, Analog Thickness Gauge), measurement range

(0.010–10.00) mm is used to determine the thickness of different pads followed by IS 7702 test method.

## Results

### Antimicrobial properties of neem-treated non-woven fabric

Neem leaves are one of the prominent natural sources which are extensively used as an antimicrobial agent due to its wide spectrum of activity and a rapid killing rate against gram-positive and gram-negative bacteria from many years ago. *Azadirachta indica* (Neem) has a potential antimicrobial activity against various strains of bacterial pathogens and shows an antimicrobial function by inhibiting the microbial growth due to cell wall breakdown (Mordue and Nisbet 2000). Several concentrations of neem extract are used as 10%, 25% and 50% in this research and the antimicrobial characteristic of the neem extract-treated non-woven fabric against *S. aureus* and *E. coli* are tabulated in Table 2. The result indicates that neem extract effectively reduces the growth of both organism as no antimicrobial activity was observed against *S. aureus* and *E. coli* in untreated non-woven fabric (Fig. 3).

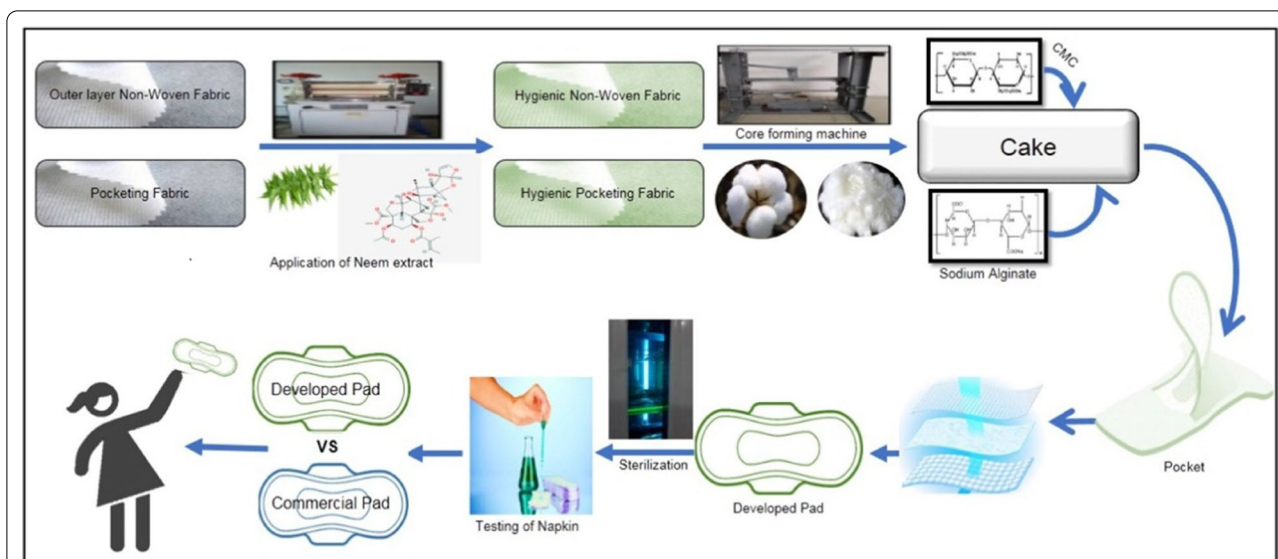
Neem extract-treated non-woven fabric, however, showed significant improvement in antimicrobial property against both organisms (Figs. 4, 5 and 6), and bacteria reduction was found to increase with increased concentration of neem extract. Lowest concentrated (10%) neem-treated samples show very good resistance against pathogenic growth where the protection reached maximum value at 50% neem-treated samples.

### Total absorptive capacity by pad

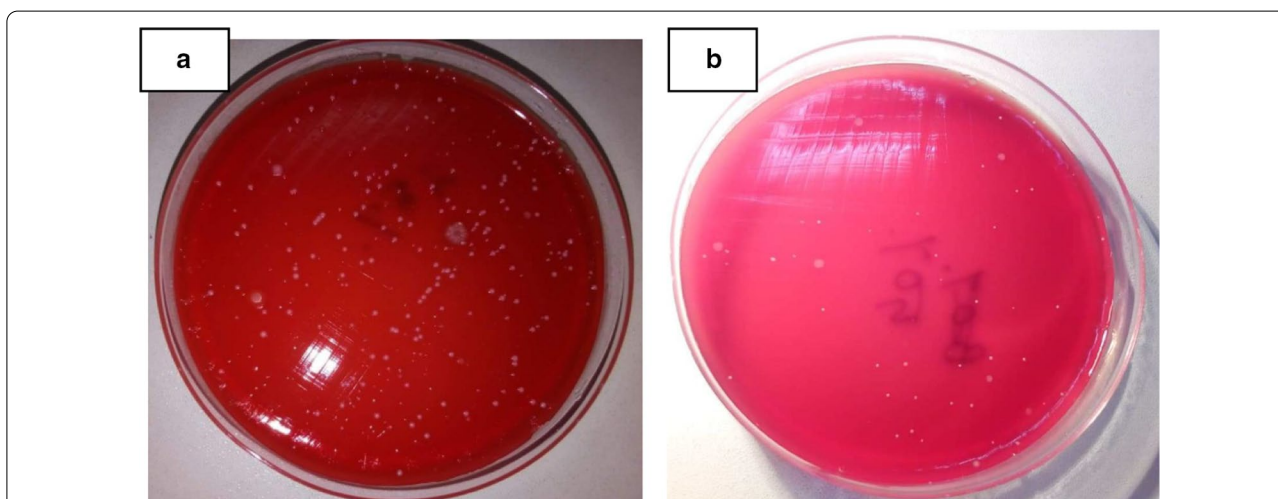
Absorptive capacity performs a significant feature in sanitary napkins, which are determined by the frequency of use without blood leakage. Absorptive capacity (amount of liquid absorbed) of sanitary napkin may be represented by the ability to absorb liquid or menstrual fluid (Fraizer 2006; Chakwana and Nkiwane 2014). The maximum absorption capacity of the pad

**Table 2 Reduction of microorganisms (*S. aureus* and *E. coli*) in treated non-woven fabric with the increment of neem extract concentration**

Test fabric samples	Surviving cells after 1 h contact time (CFU/mL)		Reduction (%)	
	<i>S. aureus</i>	<i>E. coli</i>	<i>S. aureus</i>	<i>E. coli</i>
Untreated	$2.32 \times 10^5$	$2.25 \times 10^5$		
10% neem extract	$52 \times 10^3$	$61 \times 10^3$	77.59	72.88
25% neem extract	$28 \times 10^3$	$33 \times 10^3$	87.93	85.33
50% neem extract	$10 \times 10^3$	$12 \times 10^3$	95.69	94.67



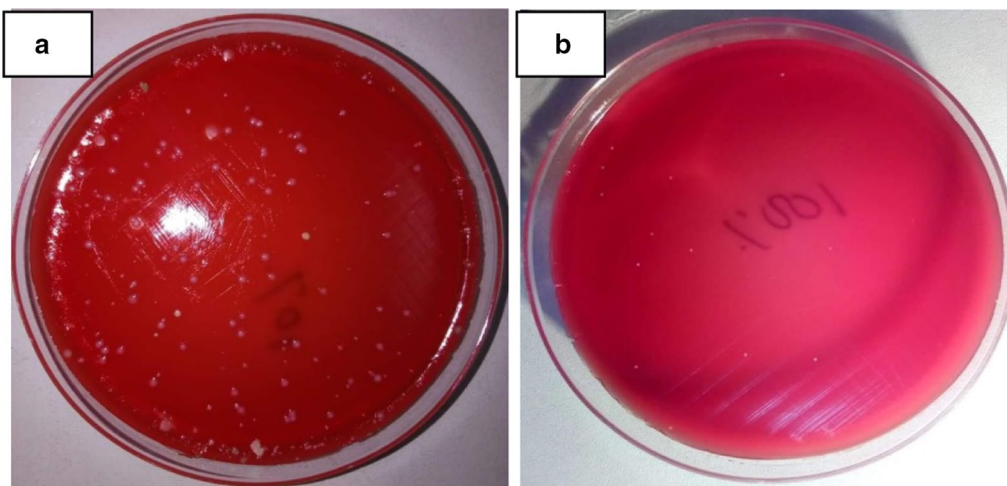
**Fig. 3** Graphical representation of the research work



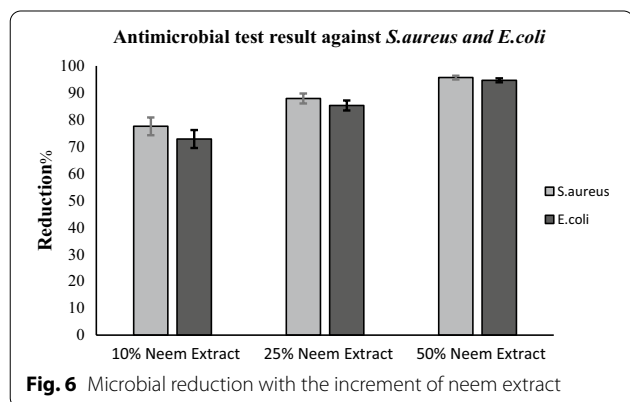
**Fig. 4** Number of surviving cells (*S. aureus*) after contact with untreated non-woven fabric sample (a) and non-woven fabric sample treated with 50% neem extract solution (b)

was defined as the total volume of saline poured onto the pad before the pad could no longer absorb saline, i.e. the last saline droplet remained on the pad surface for more than 10 min (Chatchai et al. 2007). The absorption experiment was performed using saline solution to assess the absorption capacity of the pad samples. Absorptive capacity of developed pad samples was evaluated and contrasted with chosen commercially accessible feminine sanitary napkins. Figure 7 summarizes the comparison of total absorption capacity of developed sanitary napkin against commercial

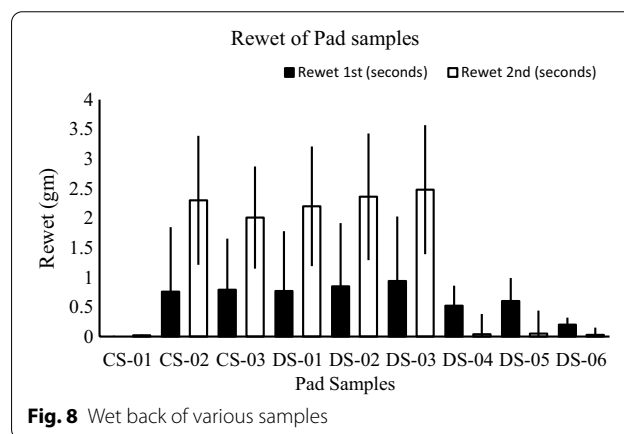
sanitary napkin. The highest absorptive capacity for sample, CS-01 (63.6 gm), is observed among three commercial samples. On the other side, the absorption capacity of the sample CS-02 and CS-03 is low owing to the use of absorbent fibre only. The absorption capacity of the samples DS-01 and DS-03 is lower among the developed pad samples, but these samples are comparable to CS-02 and CS-03. However, the developed pad samples (DS-02, DS-04 and DS-05) display improved absorption capacity. In the same way, the highest absorption capacity (63.20 gm) of the developed sample is recorded for the DS-06 sample.



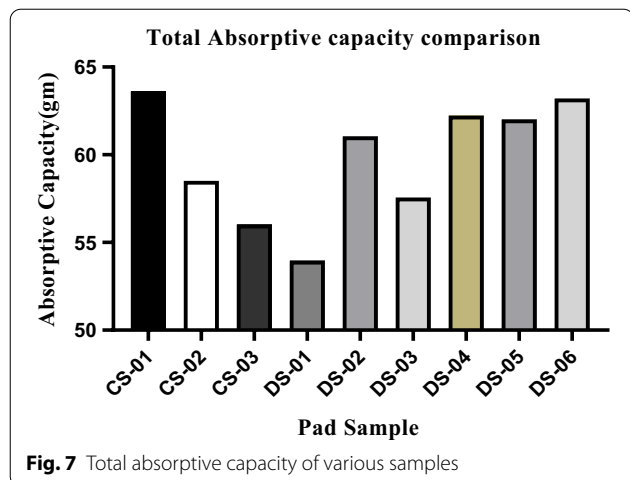
**Fig. 5** Number of surviving cells (*E. coli*) after contact with untreated non-woven fabric sample (a) and non-woven fabric sample treated with 50% neem extract solution (b)



**Fig. 6** Microbial reduction with the increment of neem extract



**Fig. 8** Wet back of various samples



**Fig. 7** Total absorptive capacity of various samples

**Rewet or wet back test**

Wet back testing is particularly important for any sanitary napkin to examine the pad’s ability to resist transportation back to the skin of a liquid that has so far penetrated the cover stock. Wetback (or rewet) is a phenomenal characteristic for assessing the quantity of liquid released by the product after absorption when the product is subjected to pressure (2.22 kg or 4.8 lb) (Mohammad 2008; EDANA 2018). Figure 8 demonstrates a comparison of the wetback properties of the engineered pad samples against commercial pad samples. As noted, the wet back property of the commercial sample (CS-01) is excellent, whereas CS-2 and CS-3 have moderate wet back properties. Although the wet back value of the developed pad samples (DS-01, DS-02, and DS-03) was not as good, it can be compared with commercial samples (CS-2 and CS-03). On the other hand, the wet back properties of the developed samples (DS-04 and DS-05) were good due to

the use of absorbent fibre and absorbent chemicals inside the core layer. Similarly, the developed sample (DS-06) showed very good wet back properties when compared to the commercial sample (CS-01).

**Acquisition time/strike through test of pad**

Strike through/penetration time is a measure of the speed at which the liquid has been transported from the surface of the pad to the inside. High strike through properties illustrates that the upper surface of the skin is readily absorbed by the pad and keeps the skin feeling dry, avoiding any feeling of wetness and eventually contributes to comfort while wearing a pad (EDANA 2018). The strike through properties of the developed pad samples compared to commercial pad samples is shown in Fig. 9. The strike through properties of commercial sample (CS-01) was higher than other commercial samples (CS-02 and CS-03). However, commercial pad samples (CS-01) show

a better strike through properties compared to other commercial and developed pad samples as they took the least time to strike. On the other side, samples CS-02, CS-03, DS-01 and DS-03 revealed poor performances. However, the developed pad samples DS-02, DS-04 and DS-05 give a reasonable strike through as they contribute significantly to liquid transport from the upper surface to the interior at a very high speed. A similar trend was observed for sample DS-06, which took exactly the same acquisition time (3 s) as the commercial sample CS-01.

**Retention capacity after centrifugation**

Retention capability for sanitary napkin is a very important characteristic that usually measures the pad’s ability to manage menstrual fluid before leakage. Different methods are used for sanitary pads and panty liners to assess the retention capacity of the products after centrifugation, as women have to work with their daily household tasks in accordance with other physical movements, such as sitting, running and walking during menstruation, to keep themselves dry before leakage, which eventually provides comfort against external pressure. Different techniques for assessing retention ability (absorption before leakage) have been established (EDANA 2018). Table 3 reveals the retention ability of all samples, and Fig. 10 illustrates the comparison of all samples. The highest retention capability was considered for commercial sample CS-01 as viewed. In contrast, the CS-02 and CS-03 commercial samples showed very poor retention capacity. Similarly, DS-01, DS-02 and DS-03 samples show poor retention capacity similar to commercial CS-02 and CS-03 samples. However, owing to the use of eco-friendly chemicals inside their key layer,

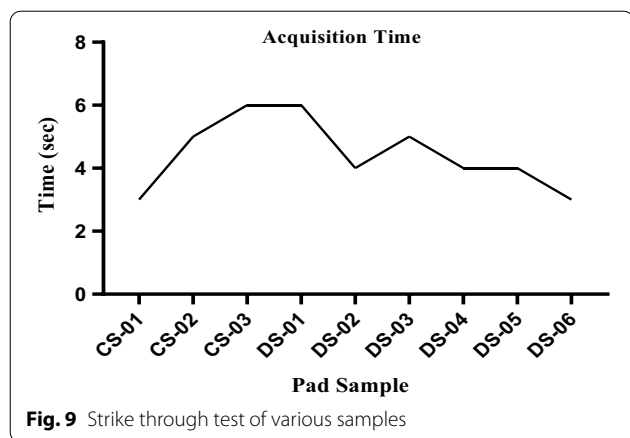
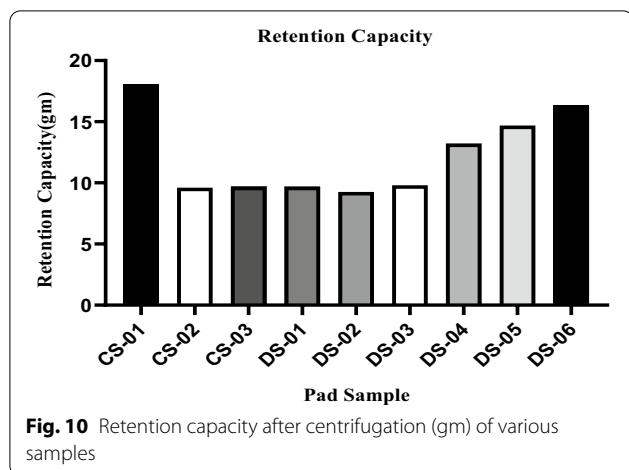


Fig. 9 Strike through test of various samples

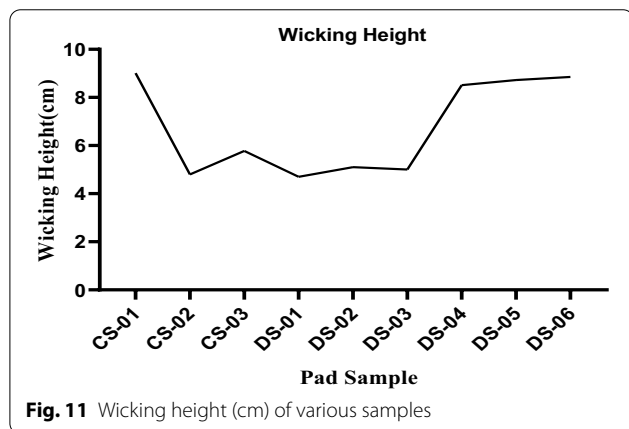
**Table 3 Comparison of quality between commercial and developed pad samples**

Sample no.	Sample name	Total absorptive capacity (gm)	Retention after centrifugation (gm)	Rewet		Acquisition time (s)	Wicking height cm
				First (gm)	Second (gm)		
01	Commercial Sample-01	63.6	18.07	0.00	0.02	3	9.01
02	Commercial Sample-02	58.5	9.60	0.76	2.3	5	4.80
03	Commercial Sample-03	56.01	9.67	0.79	2.01	6	5.78
04	100% Cotton	53.95	9.67	0.77	2.2	6	4.70
05	50% Cotton + 50% Viscose	61.01	9.25	0.85	2.36	4	5.10
06	33.3% Cotton + 33.3% Viscose + 33.3% Tissue Paper	57.55	9.79	0.94	2.48	5	5.00
07	50% Cotton + 50% Viscose, 1 gm Sodium Alginate is added	62.22	13.20	0.52	0.04	4	8.51
08	50% Cotton + 50% Viscose, 1 gm CMC is added	62.01	14.67	0.6	0.05	4	8.72
09	50% Cotton + 50% Viscose, 1 gm CMC and 1gm Sodium Alginate is added	63.20	16.30	0.20	0.03	3	8.85





**Fig. 10** Retention capacity after centrifugation (gm) of various samples



**Fig. 11** Wicking height (cm) of various samples

the retention capability for engineered samples DS-04 and DS-05 seems to be much better. Hence, the highest retention capacity among created samples is for sample DS-06.

**Measurement of wicking height**

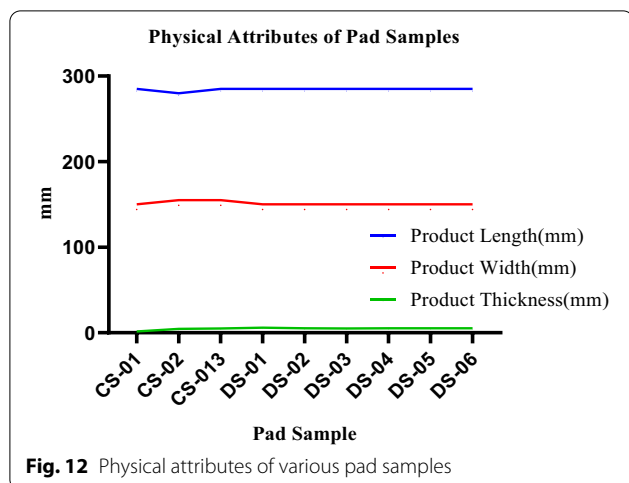
Wicking is an absolutely fundamental quality of sanitary pads as they allow the blood to be distributed throughout the pad’s entire structure while allowing the accumulated blood to be retained and distributed in the pad, thereby reducing leakage (Das et al. 2008). This test method was used by capillary action accompanied by the AATCC TM 197-2011 standard to assess the ability of vertically aligned pad specimens to transport liquid through them. Figure 11 demonstrates the wicking height results in a 1% direct dye solution. As can be seen from the graph (Fig. 11), the wicking height of the commercial sample CS-01 was greater than that of all the developed samples (DS-01 to DS-06). Interestingly, the wicking height decreases for commercial samples CS-02 and CS-03. Similarly, due to containing hydrophilic fibres only in their core layer, the wicking height of some samples developed DS-01, DS-02 and DS-03 was poor. On the other hand, some of the developed samples (DS-04, DS-05 and DS-06) reveal much better results while comparing the wicking height in a 1% direct dye solution.

**Physical properties of sanitary napkin**

Table 4 and Fig. 12 illustrate the comparison of physical characteristics among various sanitary napkin pad samples used in this research. All of the nine samples used in this experiment have a product width of between 150 and 155 mm, followed by commercial samples (CS-01 to CS-03) and newly developed samples (DS-01 to DS-06). The weight of the commercial samples was regarded as a standard weight during the development of sanitary napkin as the quality of sanitary napkin depends on the size and weight. From Fig. 12, it is shown that the weight of all developed samples (DS-01 to DS-06) is between 7 and 8 g, which incorporates comfort and protection against blood leakage during the use of sanitary napkin. The length of each sanitary napkin pad sample hereby is kept

**Table 4** Physical attributes of various sanitary napkin pad samples

Sample no.	Sample name	Product length (mm)	Product width (mm)	Product weight (gm)	Product thickness (mm)
01	CS-01	285	150	8.01	1.54
02	CS-02	280	155	7.98	4.5
03	CS-03	285	155	7.6	5.01
04	DS-01	285	150	7.97	6.02
05	DS-02	285	150	7.7	5.20
06	DS-03	285	150	7.6	5.02
07	DS-04	285	150	7.8	5.20
08	DS-05	285	150	7.8	5.23
09	DS-06	285	150	7.9	5.11



**Fig. 12** Physical attributes of various pad samples

at 285 mm, which is the standard size according to various established branded products and eventually preferable to consumers providing additional protection against leakage both day and night. Thickness along with absorbency is a basic requirement for sanitary napkin since it is not desirable and convenient to use a thicker napkin (Das et al. 2008). The length, width and thickness of the developed samples and commercial samples can be seen in Fig. 12. Consequently, Fig. 12 and Table 4 demonstrate a significant improvement in thickness and weight with an increase in the mass of the absorbent core blended web portion. The thickness of commercial samples (CS-01) is significantly lower relative to other samples incorporating an additional advantage for ultra-thin sanitary napkin, whereas CS-02 and CS-03 are thicker due to the use of cotton or other hydrophilic fibres. Commercial sample average thickness (CS-01) is 1.54 mm which is smallest due to the use of SAP, microfibres and wood pulp inside the base layer where newly developed pad samples (DS-01 to DS-06) were slightly thinner than commercial samples (CS-01). The thickness value of developed pad samples (DS-01 to DS-06) ranges from (1.6 to 4 mm) as the absorbent layer of the developed sample is made from cotton, viscose, CMC and sodium alginate. Among the developed samples (DS-01 to DS-06) the lowest thickness value is 1.6 mm for (DS-06) which is remotely similar to commercial (CS-01) samples.

## Discussion

### Antimicrobial properties of neem-treated non-woven fabric

Previous studies show that neem plays a key role as an active agent against human pathogenic bacteria (Maragathavalli et al. 2011) because of the presence of multiple antimicrobial active ingredients in neem tree leaves, such as desactylimbin, quercetin and sitosterol. Moreover, the

presence of high concentrations of azadirachtins, quercetin and  $\beta$ -sitosterol in *Azadirachta indica* (Neem) leaves might be responsible for strong antimicrobial, antibacterial and antifungal activity compared with bark and seed (Subapriya and Nagini 2005). This result is also reflected in the current experimental result when non-woven fabric is treated with 50 per cent neem extract solution.

As a consequence of this studies, neem extract is used to treat the non-woven fabric that incorporates antimicrobial function throughout the pads to make them user-friendly and comfortable. Non-woven fabrics treated with 50 per cent (w/v) neem concentration reveal improved performance, whereas all sanitary napkin pad samples are developed from these fabric samples (sample DS-01 to sample DS-06). Nonetheless, no more inquiries were made into the relative relationship between neem extract concentration and antimicrobial quality due to adverse effects on the pad's handling properties.

### Total absorptive capacity by pad

The absorption capacity of the commercial sample (CS-01) increased when super-absorbent polymers, such as polyacrylates, were adopted into the soft cellulose natural fibre pulp, which incorporates an enormous amount of water absorbency with sufficient breathability and flexibility (Zohuriaan-Mehr et al. 2010). The absorption capacity of several samples (CS-02, CS-03, DS-01 and DS-02) decreased due to the use of absorbent fibres only in the core layer. On the contrary, the absorptive capacity of the developed sample (DS-02, DS-04, DS-05 and DS-06) is boosted by the incorporation of absorbent fibres such as cotton and viscose together with CMC and sodium alginate inside the core layer as an alginate containing large amounts of hydroxyl group, COOH groups and hydrophilic carboxyl group of CMC which really contributes to the absorption of a lot of water (Tang et al. 2014). Although the commercial pad sample (CS-01) has a slightly higher absorptive capacity compared to newly developed samples (DS-01 to DS-06), but by using absorptive textile fibre such as viscose and eco-friendly available chemicals such as sodium alginate, CMC can eliminate environmental problems and offer not only safe environmental disposal but also body hygiene and comfort by minimizing irritation and other health issues on prolonged contact to human body (Berkley 1987; Yadav et al. 2016).

### Rewet or wet back test

The improvement in the wet back property of the commercial sample (CS-01) is due to the addition of super absorbent polymers (SAP) which are lightly cross-linked polymers that swell when wet (Zohuriaan-Mehr et al. 2010). On the contrary, the reason behind the mild wet

back properties for samples (CS-02, CS-03, DS-01, DS-02 and DS-03) is related to the use of absorbent textile fibres only inside their key layer. Absorbent fibres can absorb fluid quickly but could not retain it effectively, as it was connected by means of weak hydrogen bond and van der Waals force. In addition, DS-4 and DS-5 displayed better wet back functionality as it comprises sodium alginate and CMC inside the key layer. Because highly hydrophilic carboxyl group of CMC could absorb a lot of water to fill up pores, it would lead to a large space to engage water molecules as hydrogels. Among the samples developed, the wet back value for the sample DS-6 is higher due to the inclusion of sodium alginate and CMC along with 50% cotton and 50% viscose fibre to the core layer. As a result, the increased number of negative charges ( $\text{COO}^-$ ) of CMC and sodium alginate in gels enhanced the repulsion of the molecular chains, leading to the enlargement of the mesh and to the promotion of water uptake (Tang et al. 2014). In addition, sodium alginate not only provides better wet back properties, but also replaces SAP that takes several years to degrade.

#### Strike through

A better strike through property depends on the use of super absorbent granules such as SAP in the core layer of the pad (Das et al. 2008). As noted, the strike through properties of samples CS-02, CS-03, DS-01 and DS-03 was poor as the core layers of these samples were manufactured with absorbent textile fibres that can absorb fluid easily but not so fast compared to absorbent polymers. The justification for this high strike through property of the constructed samples (DS-02, DS-04 and DS-05) was owing to the use of increasing amounts of CMC, sodium alginate and hydrophilic textile fibres inside the key layer that can absorb the liquid as fast as possible. In addition, the developed sample DS-06 showed excellent properties as it took the least time to transport the saline solution from the upper surface of the pad to the inside. Sodium alginate is a well-known hydrophilic polysaccharide as cellulose and eventually increases the hydrophilicity of the hydrogels, contributing to a greater equilibrium swelling proportion. In addition, high sodium alginate content and CMC incorporate excellent hydrophilic characteristics, resulting in an increase in water absorption capacity within a very short period of time (Chang et al. 2009).

#### Retention capacity after centrifugation

Among three commercial samples, the highest amount of retention capacity is observed for the CS-01 sample (18.07 gm), which displays better retention potential. Since commercial sample core layer is usually designed with superabsorbent gels (SAP) that can absorb and

retain liquid, as a consequence, these gels swell and hold the absorbed liquid in a solid and rubbery condition that prevents any leakage (Chakwana and Nkiwane 2014). On the other hand, for several samples CS-02, CS-03, DS-01, DS-02 and DS-03, the lower retention capacity is exhibited as the core layer of these pads designed with only absorbent fibres capable of absorbing liquid but not capable of retaining liquid as much as the absorbent polymer has contributed. Incorporation of CMC and sodium alginate together with absorbent textile fibres (cotton and viscose) as key layer material resulted in the improvement in created pad samples DS-04 and DS-05. Sample DS-06 (16.30 gm) is noted to have the highest retention ability among the created sample. Since, with the contact of liquids, sodium alginate and CMC are readily transformed into hydrogels and eventually create a film that drives to maximum liquid absorption and retention potential under external pressure. In addition, the water absorption of the hydrogels improved with an increase in CMC content in the hydrogels, which can hold a huge amount of liquids against external pressure (Tang et al. 2014). The rise in the retention ability of the developed sample DS-06 in (Fig. 10) is therefore very obvious. Nevertheless, there was no analysis or assessment in this research of the better combination of these eco-friendly biopolymers and their proper physical shape and chemical alteration to improve their storage ability, such as commercial goods.

#### Measurement of wicking height

The maximum wicking height was recorded for the commercial sample CS-01, as the commercial sample consisted of superabsorbent polymer as its absorbent core. Generally, SAP is added to maximize the absorbency inside the core layer together with the other absorbent fibres, which combined effect can absorb fluid more quickly (Zohuriaan-Mehr et al. 2010). Although commercial samples CS-02 and CS-03 displayed poor wicking height as the absorbent core was engineered using only hydrophilic polymers which could not hold liquids faster than super absorbent polymer, similar trend was observed for DS-01, DS-02 and DS-03 samples as the absorbent core was intended only by fuzzy cellulosic fibres. By contrast, the wicking height of developed pad samples (DS-04, DS-05 and DS-06) gradually increases in Fig. 11 reflects the maximum absorbency of the created pad samples (DS-01 to DS-06). In addition, the developed samples DS-05 and DS-06 illustrate a maximum wicking height comparable to commercial samples (CS-01) due to the use of sodium alginate and CMC inside the core layer which can absorb water quickly. In addition, natural cellulose fibres or pulps absorb liquids through the capillary action as they have tube-like core microstructure and this

absorbency potential tends to increase dramatically when mixed with CMC and sodium alginate, since sodium alginate and CMC have gelling characteristics which allow the gel to absorb and retain the liquid throughout its distribution (Pehkonen 2001).

### Physical properties of sanitary napkin

Table 4 and Fig. 12 reveal that developed samples achieved comparable dimensions as commercial merchandise although lagging behind thickness. Non-formulation of absorbing chemicals in nanoform and inadequate alignment with base materials may be the reasons for increase in thickness. However, eco-friendly materials inside the core layer will offer the least chance of irritation when it comes to skin whereby commercial sanitary napkins available on the local market cause severe reactions during use such as rashes and even toxic shock syndrome due to use of SAP (Berkley et al. 1987). Thickness does not always show excellent absorbency, but the nature of the fibres in the pad is determined by the uptake of blood, as some fibres might be hydrophilic, whereas others be hydrophobic (Das et al. 2008). Overall, thinner napkin stands for uniform liquid distribution, which consequently ensures quality absorption of menstrual fluid as well as providing comfort while wearing sanitary napkin.

### Conclusions

Antimicrobial finished non-woven fabrics and hydrophilic cellulosic fibres were mounted in the core layer of the pad with or without encapsulation of various amounts of biopolymer, such as sodium alginate and CMC, and their use in women's hygiene products was successfully demonstrated. Some key features of pad were examined in saline solutions for all samples developed in this research and outcomes were further compared with commercially available local female sanitary napkins used during menstrual cycles for different phases. Among the samples developed (DS-01 to DS-06), DS-06 showed excellent absorption in saline solution in all conditions compared to any other commercial merchandise (CS-01 to CS-03). However, the performance of developed sanitary napkins with proportion of the commercial pad quality does not increase considerably, but the finding of this research suggests prospective implementation of biopolymer as a substitute for SAP in the absorbent napkin to provide better health conditions during menstruation. Most of the materials and chemicals used in this study are environmentally friendly, not only reducing the health risks associated with the use of SAP, but also making disposable women napkin items more environmentally friendly.

### Abbreviations

ASTM: American society for testing and materials; CMC: Carboxy methyl cellulose; CFU: Colony forming unit; CS: Commercial sample; DS: Developed sample; EDANA: European Disposables and Non-wovens Association; *E. coli*: *Escherichia coli*; ISO: International Organization for Standardization; ml: Millimetre; rpm: Revolutions per minute; *S. aureus*: *Staphylococcus aureus*; SAP: Super absorbent polymer; UV: Ultraviolet.

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### Authors' contributions

MHS and MAH conceived of the study, designed the experiment and participated in the sequence alignment and drafted the manuscript. MGN and MBH helped to coordinate experimental analysis and manuscript submission. MFH helped to revise the manuscript. All authors read and approved the final manuscript submission.

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Not applicable.

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Not applicable.

### Competing interests

The authors declare that they have no competing interests.

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