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Banana leaf extract-based emulsions for multifunctional healthcare textiles

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The study focuses on the investigation of emulsion derived from natural waste from two different varieties of *Musa acuminata,* "Red banana leaf" (RBL) and "Yellow banana leaf" (YBL) for finishing of cotton and silk fabric samples. Both the samples are treated with three different concentrations (5, 10 and 15%) of emulsions extracted from banana leaves. The antibacterial activity of the treated samples is evaluated against *Staphylococcus aureus* (*S. aureus*) and *Escherichia coli (E. coli*) bacteria. The silk samples treated with 15% RBL show significant antimicrobial activity, with 85% effectiveness against *S. aureus* and 82% against *E. coli*. The study further investigates the ultraviolet protection factor and wash durability of the treated textiles. The developed technology can be useful in addressing critical healthcare issues, offering benefits, such as antimicrobial activity, wound healing and improved patient comfort.

Keywords: Antimicrobial finishing, Banana leaf-based emulsion, Cotton, Healthcare textile, Microwave technology, Silk, Ultraviolet protection factor, Wound healing

1 Introduction

In the rapidly evolving landscape of healthcare, the role of functional textiles has become increasingly significant[1]. The global healthcare textiles market size has been estimated at USD 32.20 billion in 2022 and is expected to grow at a compound annual growth rate (CAGR) of 4.3% from 2023 to 2030[2]. Factors such as an ageing population, increased healthcare spending, and a focus on infection control are driving the demand for functional textiles[3]. In terms of applications, the healthcare and hygiene segment dominated the global industry, capturing a significant share of approx. 45% of the overall revenue in 2023. This healthcare segment encompasses diverse products like face masks, medical bags, gowns, shoe covers, wipes, bed sheets, maternity pads, incontinence pads, drapes, caps, and sanitary napkins[2]. The COVID-19 pandemic had a significant impact on several countries, leading to substantial investments to expand healthcare services, including adding hospital beds and supporting domestic production of personal protective equipment (PPE)[4].

Additionally, in hospital environments, the transmission of infectious diseases through textiles such as white coats, bed linen, curtains, and towels is well documented[5]. The significance of textile hygiene and infection control protocols has escalated in recent years, driven by the increasing apprehensions regarding the role of textiles as potential carriers of infection in healthcare environments[6]. Functional healthcare textiles serve numerous applications. These include protective surgical gowns, drapes and patient gowns, absorbency towels, and comfort bedding[7]. The current research delves into an innovative approach aimed at improving the performance of natural textiles, such as cotton and silk, within the context of healthcare textiles. Numerous researchers have examined the viability of combining natural textiles with organic and synthetic antibacterial agents to create antimicrobial textiles[8-11]. Researchers have developed advanced and smart textiles by employing nanotechnology[12]. Textiles with functional activity could either kill or stop the growth of bacteria. These investigations emphasize the potential of healthcare textiles with multiple functions to improve patient comfort and care, infection prevention, and health monitoring. The applications of these multifunctional textiles are not confined to healthcare. They also make significant contributions to

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various areas such as households, industries, sportswear, ventilation, and water purification systems[13-15].

Natural biopolymers from plant sources are gaining prominence in textiles due to their benefits. These petroleum-free substances help to reduce our reliance on fossil fuels, thereby contributing to a reduction in the carbon footprint. They may also offer cost and durability advantages over synthetic compounds. Their extraction often involves enzymes or fermentation, enhancing the synthesis of bioactive compounds. Imbuing textiles with organic biopolymers can lead to functional textiles with superior properties. Bioactive textiles, when treated with natural finishes, offer benefits like UV resistance, antimicrobial features, and insect repellency. This study explores the potential uses of banana leaf, an agricultural waste product. The main constituents of banana leaves are cellulose, hemicellulose, pectin, and lignin, as a percentage of dry mass. It has been reported that the isolated components from banana leaves such as β-sitosterol, malic acid, succinic acid, palmitic acid, 12-hydroxystearic acid, and glycoside have shown significant antimicrobial activity[16]. It has been reported that dopamine, a bioactive compound responsible for antimicrobial activity, is present in greater abundance in RBL (54 μg/g) than in YBL (42 μg/g). Additionally, the antimicrobial activity of RBL can be attributed to the presence of gentisic acid, ferulic acid, lupeol, and 3-carene[17]. Furthermore, it has been reported that the fatty acids observed in banana peel extract are also responsible for its antimicrobial activity[18]. Therefore, these compounds could potentially contribute to the antibacterial properties of textiles treated with banana leaf extract. The extraction of biopolymers from natural sources is a crucial stage in the advancement of functional textiles. Several energy-efficient extraction methods are more environmentally sustainable and ecologically benign than traditional ones. Microwave-assisted extraction (MAE), a contemporary extraction method, has gathered considerable interest[19]. MAE is an innovative and effective method to extract compounds from different plants. It is considered environmentally benign since it utilizes non-toxic solvents, making it efficient and eco-friendly. It outperforms conventional extraction techniques in multiple aspects, such as decreased solvent consumption, shortened processing time, consistent results, improved recovery efficiency, higher selectivity, and simplified sample handling. Use of MAE has the potential to enhance the extraction of bioactive components from banana leaf extract, hence increasing the effectiveness of the resultant textiles. In textiles, cotton and silk with their unique attributes, have been vital to healthcare textiles for centuries. Cotton, typically employed in external applications like surgical attire, covers, bedding, and internal applications such as wound dressing, tissue engineering, drug delivery, surgical and dental applications, offers comfort, safety, and hygiene in patient care[2,20]. Similarly, the mechanical properties, biocompatibility, biodegradability, and implantability of silk fabric make it effective in functional textiles[21]. Furthermore, no work has been carried out on the development of functional textiles finished using banana leaf-based emulsions. The addition of an emulsion derived from banana leaf extract could potentially enhance the functionality of these textiles, offering additional health benefits and enhancing the overall textile quality[16-18]. This study concentrates on applying this banana leaf extract emulsion onto two distinct natural textiles, cotton and silk fabric samples. The research aims to foster the sustainable development of functional textiles by utilizing natural waste materials, thereby promoting health and wellness in an environment-friendly manner.

2 Materials and Methods

Two different varieties of banana leaf, viz yellow banana leaf (YBL) and red banana leaf (RBL), were collected from the field and dried under shade until the moisture was reduced as much as possible. The collected samples were crushed into powder form using an electric mixture. The 1000 g of banana leaf extract was found to be 940 g and 925 g for YBL and RBL respectively. The extracted powder is used for solvent extraction using ethanol. Further, the rotary evaporator is used for the extraction of solvent. The yield % for YBL and RBL was observed to be 2.32 and 2.26 respectively. Both cotton and silk plain woven fabrics were treated with three different concentrations (5, 10 and 15%) of YBL and RBL based emulsion using microwave technology. Three different concentrations of optimized emulsion were chosen to find the minimum and maximum effect of the treatment on different textile structures. Table 1 shows the fabric characteristics of both cotton and silk fabric samples.

Table 1 — Fabric characteristics

Particular	Cotton	Silk
Weave type	Woven	Woven
Mass per unit area, g/m^2	100	100
Yarn density (warp × weft)	(56 × 44)	(44 × 41)
Tensile strength, N	225	175
Elongation at break, %	7.5	11
Thickness, mm	0.2	0.1
Cover factor	18.4	19.6

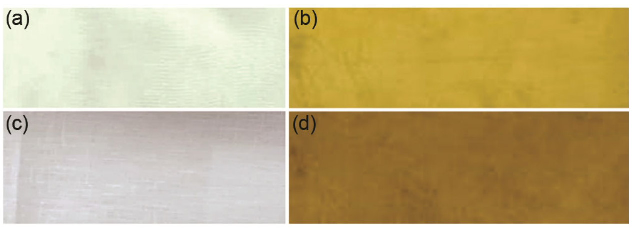

Fig. 1— Air-dried samples of (a)untreated silk, (b)15% RBL treated silk, (c) untreated cotton and (d) 15% RBL treated cotton

2.1 Preparation of Emulsion

The emulsion was prepared by diluting a water/surfactant mixture with water at 27^{o}C temperature[22]. The surfactants employed were polysorbate 80 (Tween 80) and span 80 (Sorbitanmonooleate). The treatment process involved the use of microwave technology at 100^{o}C for 10min. All test samples were immersed in an optimized concentration of emulsion prepared with acetone, maintaining a material-to-liquor ratio of 1:25. Subsequently, the treated samples underwent an air-drying process. This process is depicted in Fig. 1, which specifically illustrates the air-dried samples. The add- on % is calculated using the following formula:

$$\text{Add- on } (\%) = (A- B) \times 100/ B \quad \dots (1)$$

where A is dry weight of the biopolymer finished sample; and B, the dry weight of the sample before finish.

The evaluation of fabric tensile strength was performed in compliance with the ASTM D5035 standard, utilizing a Tinus Olsen universal tensile tester. An average of 5 readings were taken for the study. The surface morphology of the test samples was examined using a JEOL's scanning electron microscopy. The Fourier transform infrared spectroscopy was carried out for the detection of functional groups by using the Bruker Alpha model. The ASTM D737 test standard was adhered to for the measurement of air permeability. In accordance with ASTM D570, the water retention capacity of the treated samples was determined. The AATCCTM197 (2018) test method was used to assess the wicking behaviour, which is characterized by the vertical movement of moisture through the fibre channel. The assessment of rubbing fastness was performed using a crock meter following the standard BS EN ISO 105–X12:2016. The test specimen was rubbed with both dry and wet clothes, and the level of discolouration was evaluated employing a colour gray card. This assessment provides the colour fastness grade. For the wash fastness of test samples, a standardized washing procedure in a Launder-o-meter, following the ISO 105-C06 test standard was used. The light fastness test was performed using the AATCC 16 test method, with a Xenon lamp test instrument serving as the light source. The ultraviolet protection factor (UPF) for treated samples was evaluated using a Gester UPF tester in accordance with AATCC 183-2004 test method. The antibacterial activity of test samples was evaluated qualitatively by the parallel streak method (AATCC- 147) and quantitatively by the colony count method (AATCC 100) using *S. aureus* (Gram-positive) and *E. coli* (Gram-negative) bacteria. In the colony count method, the antibacterial activity of the treated samples was determined by calculating the per cent reduction in the number of colonies compared to the untreated samples, using the following formula:

$$\text{Antibacterial activity or \% reduction} = (U\text{-}T)/ T \times 100$$

where U is the bacteria colony (colony forming units/ml) of control samples; and T, the bacterial colony of the treated swatches.

The treated fabrics were then washed in a launder-o-meter according to the AATCC test method 124-1975 (II A) using Lissapol N, a non-ionic detergent to check the durability of the treated fabric samples.

3 Results and Discussion

3.1 Effect on % Add-on

All treated samples exhibit an increase in mass. Table 2 presents the percentage add-on results before and after treatment. It has been observed that a higher concentration of the finish correlates with an increased percentage add-on in the treated fabric samples, attributed to the attachment of bio particles extracted onto the fabric surface. The cotton fabric sample, treated with a 15% RBL-based emulsion, demonstrates a maximum add-on of 9.52%. Similarly, the silk fabric exhibits a maximum add-on increase of 14.29% finished with a 15% RBL-based emulsion. In case of silk fabric samples, the treatment at a temperature of 100^o C induces structural swelling, facilitating the permeation of bio-compounds into the polymer chain. This causes a restructuring of the molecular formation, which alters the characteristics of the silk fabric, allowing more particles to enter its complicated structure. The degree of modifications depends on the extent of swelling and molecular alignment.

Table 2 — Effect of banana leaf-based emulsions on add-on %

Fabric	Concentration, %	Add-on %	
		YBL	RBL
Cotton	5	2.62	4.42
	10	5.49	7.99
	15	9.50	9.52
Silk	5	2.12	3.96
	10	6.62	8.25
	15	10.39	14.29

3.2 Effect on Surface Morphology

The surface morphology of the test specimens is examined using scanning electron microscopy. Figs 2(a) & (b) show the influence of the extracted bio compounds from the banana leaf extract on the surface of cotton fabric. Figure 2(b) indicates a uniform distribution of these bio compounds across the fabric surface. Furthermore, Fourier Transform Infrared (FTIR) analysis is conducted to verify the presence of functional finishes on the surface of the treated samples. The FTIR spectra is recorded in the 500-4000 cm^{-1}wavenumber range. Figures 3(a) & (b) display the presence of YBL and RBL compounds in the treated cotton and silk fabrics in a wide peak stretching at around 3000 to 3500 cm^{-1} corresponding to OH stretching.

3.3 Effect on Tensile Strength

Table 3 illustrates the impact of varying finish concentrations of YBL and RBL on treated fabric samples. The results indicate a decline in the retention percentage with an increase in the finish concentration, both in warp and weft directions. The

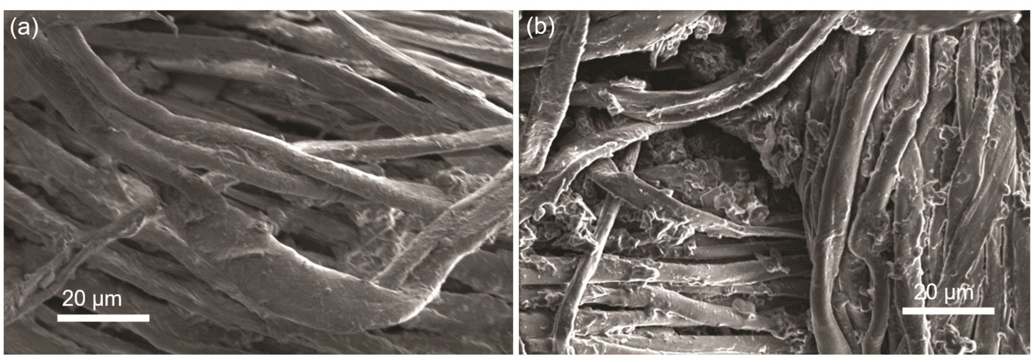

Fig. 2 — SEM images of (a) untreated and (b) 15% RBL treated cotton samples

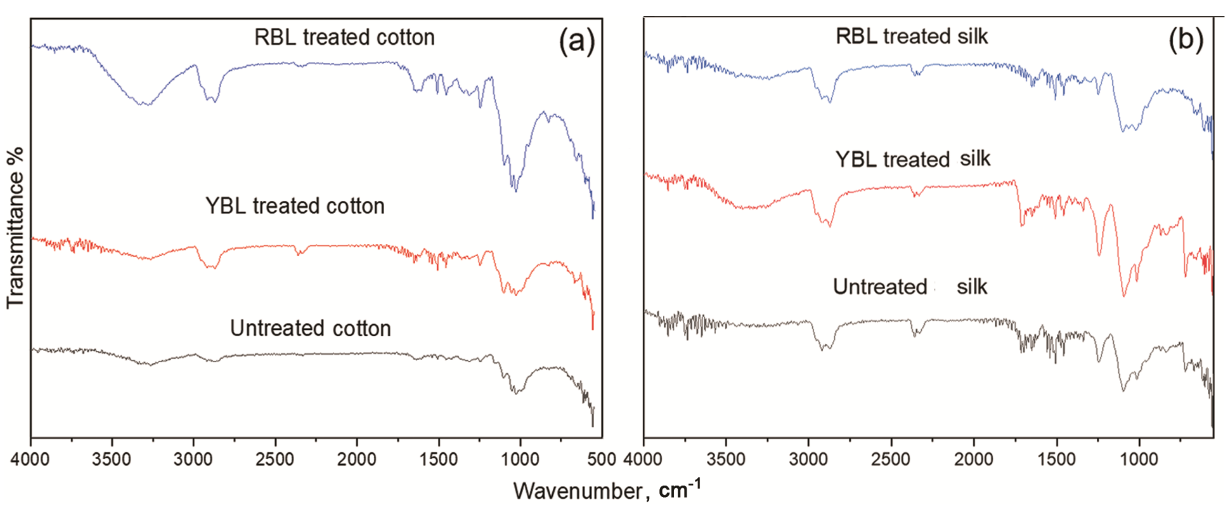

Fig. 3 — FTIR analysis of untreated and treated samples of (a) cotton and (b) silk

Table 3 — Effect of banana leaf-based emulsions on tensile strength

Fabric	Concentration, %	Tensile strength, N					
		YBL			RBL		
		Control	Treated	Retention, %	Control	Treated	Retention, %
Cotton (warp)	5	220.64	184.5	83.62	220.64	186.4	84.48
	10	220.64	179.3	81.26	220.64	181.5	82.26
	15	220.64	165.2	74.87	220.64	169.3	76.73
Cotton (weft)	5	144.14	138.6	96.16	144.14	140.2	97.27
	10	144.14	132.5	91.92	144.14	134.8	93.52
	15	144.14	122.3	84.85	144.14	126.4	87.69
Silk (warp)	5	175.53	168.4	95.94	175.53	172.6	98.33
	10	175.53	148.2	84.43	175.53	151.4	86.25
	15	175.53	138.5	78.90	175.53	141.7	80.73
Silk (weft)	5	101.98	93.7	91.88	101.98	95.4	93.55
	10	101.98	88.6	86.88	101.98	90.4	88.64
	15	101.98	82.5	80.90	101.98	86.3	84.62

Table 4 — Effect on wicking, water absorption, air permeability and UPF

Fabric	Concentration, %	Wicking cm		Water absorbency, %		Air permeability cc/s/cm^2		UPF	
		YBL	RBL	YBL	RBL	YBL	RBL	YBL	RBL
Cotton	Control	4	4	10	10	19.64	19.64	40.4	40.4
	5	4.6	4.8	13.94	14.26	13.53	12.32	48.2	49.2
	10	5.2	5.7	17.87	18.44	9.45	8.24	56.4	58.1
	15	6.5	6.9	22.34	23.12	6.09	7.63	62.2	64.3
Silk	Control	6.5	6.5	5	5	28.45	28.45	45.5	45.5
	5	7	7.2	6.92	7.34	18.61	16.11	51.3	52.4
	10	7.4	7.7	7.45	8.80	13.54	12.10	57.8	58.6
	15	7.6	8	9.30	9.95	10.33	9.39	68.8	73.5

maximum strength loss is observed in the warp direction for both cotton and silk-treated samples. Further, it is observed that cotton (warp direction) treated with 15% YBL-based emulsion shows a 25.13% reduction in tensile strength. Conversely, the weft direction YBL-based emulsion with 15% concentration shows a 15.15% reduction in tensile strength. Similarly, samples treated with 15% RBL-based emulsion show reductions of 23.27% and 12.31% in the warp and weft directions respectively. The reduction in strength could be attributed to the attachment of extracted bio particles onto the fabric surface during the finishing process.

The chemical interaction of bio molecules might alter the fabric's structural regularity by potentially weakening the bonds and increasing the surface irregularity, thereby affecting the overall strength of the fabric. Comparable results are observed in the case of silk fabric treated with different concentrations of YBL- and RBL-based emulsions. The maximum strength reduction of 21.1% is observed in the case of 15% YBL-based emulsion treated silk samples (warp direction), whereas, in the weft direction, the strength loss is observed to be 19.1%. The higher retention% in the case of RBL may be due to the high concentration of bioactive compounds in RBL.

3.4 Effect on Wicking, Water Absorption and Air Permeability

Table 4 shows that the finish concentration significantly affects the wicking behavior of the treated samples. An increase in the finish concentration leads to an increase in the wicking property of the treated samples. The wicking rate increases from 20% to 72.5% with an increase in the finish concentration from 5% to 15% in the case of RBL-treated cotton samples. Similarly, 15% YBL-treated cotton samples show a maximum increase of 62.5%. The increase in the wicking rate for cotton-treated samples is observed slightly higher as compared to the wicking rate of silk-treated samples. The maximum wicking rate of 23.07% is observed in the case of RBL-treated silk fabric samples.

Table 5 — Effect on rubbing, washing and light fastness

Fabric type	Concentration, %	Rub fastness				Wash fastness		Light fastness	
		YBL		RBL		YBL	RBL	YBL	RBL
		Dry	Wet	Dry	Wet				
Cotton	5	5	4	4	4	4	4	4	4
	10	4-5	3-4	4	3-4	3	4-3	3-4	4
	15	4-5	3	3-4	3	3	3	3	3
Silk	5	5	4	5	4	5	5	4	5
	10	5	4	5	4	4	5	4	4
	15	5	4	5	4	3-4	4-5	4	4

Furthermore, the water absorption capacity of the treated samples increases with an increase in the finish concentration in both cases. The maximum absorption is 131.2% and 123.4% in 15% RBL and 15% YBL treated cotton samples respectively. Whereas the silk fabric treated with 15% concentration of RBL and YBL show 99% and 86% respectively.

However, the air permeability decreases for treated fabric samples as the concentration of the finish increases. As seen in Table 4, treated cotton fabric samples exhibit a significant decrease in air permeability values. For instance, a 15% RBL-treated cotton sample has an air permeability value of 7.63 cc/sec/cm^2, compared to 19.64 cc/sec/cm^2 for untreated samples. This decrease in air permeability can be attributed to a reduction in pore size resulting from increased finish concentration. Similar trends are observed in YBL-treated cotton fabric samples. The same pattern is also evident in YBL and RBL-treated silk fabric samples.

The ultraviolet protection factor (UPF) of the treated samples is excellent in all cases. The UPF value for cotton samples increases from 40.4 to a maximum of 64.3 in the case of 15% RBL-treated cotton samples. For these cotton samples, the UPF value increases up to 59.15%. A similar observation is made in the case of silk samples. The UPF value for silk samples increases from 45.5 to a maximum of 73.5, with an increase of 61.5% with a 15% RBL finish. This could be attributed to the increase in the finishing compound. An increased colour depth value might enhance UV absorption, leading to a higher UPF (Fig. 1).

3.5 Effect on Rubbing, Washing and Light astness

Table 5 presents the impact of rubbing, washing, and light fastness on all treated samples. Dry and wet samples of cotton treated with a 15% YBL-based emulsion exhibit excellent and good rubbing fastness, scoring 4-5 and 3 respectively. Samples treated with RBL display slightly lower rubbing fastness than those treated with YBL. Dry cotton samples treated with a 15% RBL-based emulsion show good rubbing fastness with a score of 3-4, while wet samples score 3, indicating good fastness. Similar outcomes are observed for silk-treated samples. Both dry and wet samples treated with YBL and RBL demonstrate excellent rubbing fastness, scoring 5 and 4 respectively.

The wash fastness of the treated samples is assessed post-washing in a launder-o-meter. Both 15% YBL and RBL treated samples exhibit a good wash fastness rating of 3. In contrast, silk fabric displays a good to very good fastness rating of 3-4 for YBL-treated samples and very good to excellent fastness ratings of 4-5 for RBL-treated samples. The light fastness appears to decrease with an increase in the finish concentration. The 15% YBL and RBL treated samples demonstrate a moderate light fastness rating of 3. However, silk-treated samples exhibit a good light fastness rating of 4.

3.6 Effect on Antimicrobial Efficacy

Figure 4 illustrates the antibacterial activity of cotton and silk samples treated with YBL and RBL extracts against *S. aureus* and *E. coli*. It is observed that the treatment influences the antibacterial activity of all the treated fabric samples. Figs 4(a) – (d) show that the cotton fabric samples treated with an emulsion of 15% YBL and RBL extract exhibit antibacterial activity against both *S. aureus* and *E. coli*. Similarly, Figs 4(e) – (h) display the antibacterial activity of silk treated samples against both Gram-positive and Gram-negative bacteria. It is noted that all the treated fabric samples develop an effective inhibition zone against both types of bacteria. The durability of the fabric samples has been tested using launder-o-meter using AATCC 135 test method.

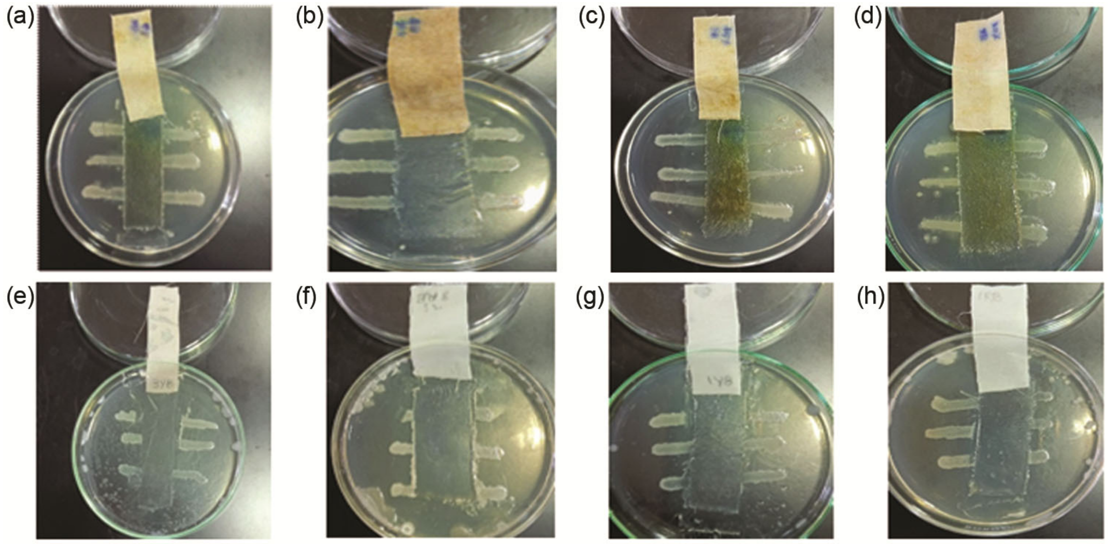

Fig. 4 — Antibacterial activity of banana leaf extract treated fabric samples (a) 15% YBL extract treated cotton sample against *S. aureus*, (b) 15 % RBL extract treated cotton sample against *S. aureus*, (c) 15% YBL extract treated cotton sample against *E. coli*, (d) 15 % RBL extract treated cotton sample against *E. coli*,(e) 15% YBL extract treated silk sample against *S. aureus*, (f) 15% RBL extract treated silk sample against *S. aureus*, (g) 15% YBL extract treated silk sample against *E. coli* and (h) 15% RBL extract treated silk sample against *E. coli.*

Table 6 — Effect of laundry on antibacterial activity

Fabric	Finish conc. %	Without laundry				15 Household washes				30 Household washes			
		S. aureus		*E. coli*		*S. aureus*		*E. coli*		*S. aureus*		*E. coli*	
		CFU/mL ($\times 10^{-7}$)	Antibacterial activity %	CFU/mL ($\times 10^{-7}$)	Antibacterial activity, %	CFU/mL ($\times 10^{-7}$)	Antibacterial activity %	CFU/mL ($\times 10^{-7}$)	Antibacterial activity, %	CFU/mL ($\times 10^{-7}$)	Antibacterial activity %	CFU/mL ($\times 10^{-7}$)	Antibacterial activity %
Control	-	72	-	80	-	72	-	80	-	72	-	80	-
YBL Cotton	5	25	65	32	61	32	56	38	54	40	44	48	41
	10	17	76	24	71	23	68	30	63	32	56	39	52
	15	15	79	21	74	21	71	27	67	30	58	36	56
RBL Cotton	5	24	67	27	67	30	58	33	60	39	46	42	49
	10	16	78	23	72	22	69	29	65	31	57	38	54
	15	14	81	19	77	20	72	25	70	29	60	34	59
YBL Silk	5	20	72	26	68	26	64	32	61	35	51	41	50
	10	15	79	22	73	21	71	28	66	30	58	37	55
	15	12	83	18	78	18	75	24	71	27	63	33	60
RBL Silk	5	19	74	24	71	25	65	30	63	34	53	38	54
	10	14	81	20	76	20	72	26	68	29	60	35	57
	15	11	85	15	82	17	76	21	74	26	64	32	61

Table 6 presents the antimicrobial activity of the samples treated with and without laundry (15 and 30 home washes). Table 6 reveals that all the samples treated without laundry exhibit substantial antimicrobial activity, ranging from 65% to 85% and 61% to 82% against *S. aureus* and *E. coli* respectively. The high concentration of bioactive compounds such as dopamine, gentisic acid, ferulic acid, lupeol, 3- carene found in RBL might contribute to its superior antimicrobial activity compared to YBL-treated fabric. It is clear from Table 6 that the laundry cycles significantly impact the efficacy of the treated samples. The antimicrobial efficacy after 15 home laundry washes range from 56% to 76% and 54% to 74%, while after 30 home laundry washes, it decreases to 44-62% against *S. aureus* and 41-61% against *E. coli*.

4 Conclusion

Two different varieties of banana leaf (YBL & RBL) extract-based emulsions have been impregnated at different concentrations (5, 10 and 15%) onto cotton and silk fabric structures. It is observed that the silk fabric demonstrated maximum antibacterial activity of 85% and 82% when treated with 15% RBL emulsion against both *S. aureus* and *E. coli*. The banana leaf extract-based emulsion finish is considered the best antimicrobial finish, showing antibacterial activity of 44-64% against *S. aureus* and 52-61% against *E. coli*, even after 30 household washes. However, the treatment does affect the tensile strength of the fabric samples, with a maximum reduction of 25.13%. The wicking behaviour is maximally improved by 72.5% and 23.07% in the case of 15% RBL treated cotton and silk respectively. Similar results are observed in the case of the water-holding capacity of treated samples. The finish significantly decreases the air permeability of treated samples, with the 15% RBL treated sample's air permeability observed to be 7.63 cc/s/cm^2. The maximum UPF value is observed to be 64.3 and 73.5 for cotton and silk treated samples respectively. The overall performance of the test specimen suggests it to be an effective material for healthcare applications.

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