LGU Journal of
LIFE SCIENCES

LGU Society of Life Sciences

DOI: https://doi.org/10.54692/lgujls.2024.0802336

Paper Submission: 26th Oct 2022; Paper Acceptance: 7th June 2024; Paper Publication: 14th June 2024

Research Article | LGU J. Life. Sci
Vol 8 Issue 2 April- June 2024 | ISSN 2519-9404
eISSN 2521-0130

Antimicrobial Polyester Textiles Based on Organic Compounds

Shama Sadaf[1*], Shagufta Naz[2], Wajeeha Salamat[2], Komal Hassan[1], Ayesha Saeed[1], Saima Sharif[2]

1. Department of Home Economics, Lahore College for Women University, Lahore, Pakistan
2. Department of Zoology, Lahore College for Women University, Lahore, Pakistan

Corresponding Author's Email: sadaf.shama@gmail.com

ABSTRACT: Microorganisms though present everywhere, but they can be prevented by a simple antimicrobial finish. In this cross-sectional study, eco-friendly antimicrobial finishes were extracted from leaves of Azadirachata indica, Butea monosperma and Litchi chinensis plants and applied on 100% polyester. The antimicrobial finish was applied by the pad dry cure method and was fixed by using of polyurethane binder. Plants 'extractions were manipulated by making two concentration levels, in one level pure plant extraction was applied and on the other level, 50% concentration dilute solution was applied. The results were analyzed through analysis of variance (ANOVA), Spectrum Analysis, Scanning Electron Microscope (SEM), photographic images, and Crosstab. The eco-friendly antimicrobial finish made 89% reduction in microbial growth. The antimicrobial finish lasted up to 25 washes. Antimicrobial fabric is suitable to provide protection against microorganisms and can be used for the medical industry, paramedical staff, sportswear, home furnishing as well as common people.

Keywords: Antimicrobial finish, Polyester, Azadirachata Indica, Butea Monosperma, Litchi Chinensis

INTRODUCTION

Microorganisms are present everywhere in surroundings such as in homes and hospitals, so human beings are frequently exposed to them. Textiles provide enormous surface zone and moisture which are required for bacterial development (Sauperl, 2016). Polyester fibres which are obtained from natural sources such as cotton and silk provide dampness, oxygen, nutrients and temperature which are the basic requirements for bacteria development and duplication. It causes bad smell, skin infection, colour and product deterioration, allergic and other allied sicknesses (Maghsoudi et al., 2021).

The new focus developed for antimicrobial treated fabric is to guard the wearer from germs as well as to guard the fabric from fibre deterioration. Now-a-days, antimicrobial textiles have received importance in industry as well as educational research because its importance is to give good quality life and protection benefits to human beings. Recently customers are demanding in textiles commonly functional treatment but specifically antibacterial treatment to guard people from bacteria (Shibly et al., 2021). There is a wide range of materials on which antimicrobial finish can be applied such as apparel for doctors, nurses, patient, premature babies, sportswear, socks, babies, older people, undergarments, soldiers, miners and in home furnishing it can be apply on bed sheets, curtains, carpets as well as common people (Rajput et al., 2017).

MATERIALS AND METHODS

In this study antimicrobial finish was extracted from three plants leaves i.e. *A. indica*, *B. monosperma* and *L. chinensis* (carried out in laboratory of Botany Department, Government College University) were applied on 100% polyester. The weights of dry powder of leaves *A. indica* (Neem), *B. monosperma* and *L. chinensis* were 2 kg each. Three airtight containers were prepared and labelled as A (*A. indica*), B (*B. monosperma*), and L (*L. chinensis*). These containers, along with distilled water, were then autoclaved at a temperature of 110 degrees to ensure sterilization. In Laminar Air Flow Hood, poured powder of leaves of *A. indica* in autoclave container A then add autoclaved distilled water. The ratio of grinded leaves and distilled water was 100 g/250 ml. This process was repeated for *B. monosperma* and *L. chinensis*. Leave this soaked material for 7 days and stirred it twice a day.

After that it was filtered by using muslin cloth then filtered again by using What man filter paper. The filtered extracts of *A. Indica* (Neem), *B. monosperma* and *L. chinensis* were concentrated by a rotary film evaporator.

Antimicrobial finish was applied in National Textile University (NTU) Faisalabad. Plants 'extractions were manipulated by making two concentration levels, in one level pure plant extraction was applied and in other level 50% concentration solution was used. The fabric samples were cut, treated with antimicrobial finish and then tested to govern their effectiveness as antimicrobial fabrics. Antimicrobial agents were extracted from leaves of *A. indica, B. monosperma* and *L. chinensis*. Binder was used to improve the durability of finish. The binder was obtained from CHT Pakistan. Antimicrobial testing was carried out in Centre of Excellence in Molecular Biology (CEMB). To check the presence of antimicrobial finish on fabrics pre-test post-test, FTIR test was conducted at the Institute of Chemistry, University of the Punjab, SEM test was conducted in The Centre for Solid State Physics, University of the Punjab, Lahore.

The study included a control group consisting of untreated fabrics without antimicrobial finish. To mitigate the impact of extraneous variables such as temperature and humidity, the research was conducted in controlled testing laboratories with standardized atmospheric conditions, ensuring a consistent environment for all experiments. There were one fabric and three plants. The antimicrobial finish was developed from plants in two concentrations that were 50% and 100% then applied on fabrics. Microorganisms' presence was checked by pre-test, post-test control group design. Antimicrobial finish was applied by making two concentration levels, in one level 100% (pure) plant extraction were applied and in other level 50% concentration solution was made. Durability of antimicrobial finish to washes was checked at 50% concentration of antimicrobial finish by repeated number of wash cycle i.e. 5 washes intervals up to 25 washes.

Microorganisms Observation

The microorganisms examined in this study were those that were isolated during the experiment. The isolates consisted of various morphological forms, including Gram-positive microorganisms such as small thick rods, clusters, cocci, and coccus clusters, as well as Gram-negative microorganisms like thin short rods, diplococci with short tails, rounded cocci, coccus-bacilli, coccus diploids, and fungi (yeast). These microorganisms were studied in Centre of Excellence in Molecular Biology (CEMB) under standard conditions.

Application of Concentrated Antimicrobial Finish

To check antimicrobial activity 100% (pure) antimicrobial leaves extract was used. The researcher took 200 ml plant leaves extract of *A. indica* which was obtained from rotary film evaporator in a beaker. Cut one foot width and three feet length fabric sample randomly from 100% polyester fabric. Four more samples of same measurements were taken, one for untreated control group and three were for experimental group. On experimental group *A. indica*, *B. monosperma* and *L. chinensis* leaves extract finish was applied by using pad dry cure method. After applying this finish microorganism's detection was checked against control group in CEMB.

The dilute concentration of finish was prepared in ratio of 200 ml leaves extract of *A. indica* (Neem), 50 ml poly urethane binder and 150 ml distilled water. Same ratio was used for *B. monosperma* and *L. chinensis*. The three meter fabric sample was taken as length and twelve inch as width from cotton fabric; label untreated (un), *A. indica* (A), *B. monosperma* (B) and *L. chinensis* (L). So, there were four samples from polyester fabric. On untreated cotton samples no finish was applied. On sample A, *A. indica* antimicrobial finish was applied, on sample B, *B. monosperma* leaves extract antimicrobial finish was applied and on sample *L. chinensis* leaves extract antimicrobial finish was applied respectively. The untreated polyester sample was the control group and the polyester samples treated with *A. indica*, *B. monosperma* and *L. chinensis* leaves extract antimicrobial finish were experimental group.

The antimicrobial finish was applied by using the pad dry cure machine in NTU. On pad dry cure machine (process) drying was done at 120°C temperatures for 2 minutes and curing was done 150°C temperatures for 3 minutes. After applying this concentration antimicrobial finish, microorganisms' presence was checked in CEMB. Sustainability of antimicrobial finish to home laundry was checked by five washes interval up to 25 washes and samples were cut according to each test requirement.

A 0.5 kg sample of Poly Urethane Binder was obtained from CHT. The binder was applied to enhance the wash durability of the antimicrobial finish. To assess the antimicrobial properties of the binder, a 1x1 feet cotton fabric sample was treated with a solution of 10ml poly urethane binder and 90ml distilled water, applied using a pad dry machine. The ASTM E2149 Shake Flask Method was employed to test the antimicrobial properties, which revealed that the binder did not exhibit any antimicrobial activity. The polyurethane binder, used as a polymeric finishing agent, had a slightly yellow colour and a pH range of 4.0-5.0.

To check the effectiveness of plant leaves, extract as antimicrobial finish on polyester fabric, cut fabric samples in Laminar Air Flow hood. The sample size for antimicrobial testing was one inch width and one inch length. Random sample was taken from untreated control group and from experimental group same size sample were cut i.e. one sample from each *A. indica, B. monosperma* and *L. chinensis* treated polyester fabric respectively.

To check presence of antimicrobial finish on fabrics ASTEM E2149 shake flask method was used. It was a quantitative screening test. The temperature of autoclave was 110oC.All the fabrics samples were cut 3cm in length and in width. Each sample was dipped in both concentrated and dilute solution of 100% *A. indica, B. monosperma* and *L. chinensis* for two hours. These samples were kept in room temperature to dry. In sterilized petri dishes took 50 ml PBS (phosphate buffer solution) in which fabric samples were soaked individually for one hour with continuous shaking. Label all petri dishes which have both treated and untreated fabric samples. Next, inside a Laminar Air Flow Hood, agar plates were prepared by precisely dispensing 50 microliters of solution using a pipette adjusted to a volume of 50 microliters.

In Laminar Air Flow Hood took a spreader, first dipped in spirit then put on spirit lamp until it became red, cooled down it. Fifty micro litre solution of plant leaves extract (with sterilized nozzle, which change every time) and poured on agar plate. Petri dish was put on rotator and with the help of spreader, spread the drop in clockwise direction. Cover it and put it in incubator which set at 37-40°C temperature. First reading was taken after 22 hours and then counted the number of colonies in range of 20-200, 30-300, colonies more than 2000 which called uncountable or lawn. After six days reading was taken again.

In Laminar Air Flow Hood, put petri dishes, slides, spirit lamp, pipette man, wire stick and distilled water. Adjust pipette man at 10 microliters. Took a slide, put a drop of distilled water. Then took iron wire stick, dipped in spirit, heated it on spirit lamp until its colour was red, cooled down it. Took only those petri dishes on which microorganism's presence was shown by use of colony counter and spread gently on glass slide until it was fully dissolved in distilled water. Dried it on spirit lamp with help of tweezer and staining was carried out.

Put slide on frame. Flood smear with methylene blue (injected methylene blue in the smear) and left it for one minute. Drained it with iodine solution and left it for one minute. Washed it with distilled/tap water. Drained it with decolourizer. At the end floods with methylene red dye and left for one minute. Then washed it. After drying these slides microorganisms' presences were checked on microscope and observation were noted.

Sustainability in home laundry

The washing of fabrics samples was checked by using AATCC test method 135-2003. Following apparatus was used, Automatic washing machine , Automatic tumble dryer, Conditioning/drying racks with pull-out screens or perforated shelves, Facilities for drip drying and line drying and 1993 AATCC Standard Reference Detergent.

Cut the sample from fabric in standard testing atmosphere. Samples were placed on the flat surface. Automatic washing machine did laundry by the following steps as washing, rinsing, and drying. In washing, automatic washing machine weights the fabric samples. According to sample size water level was selected. The temperature for washing and rinsing was less than 29°C. Add 1993 AATCC standard reference detergent by the ratio of 1g/l. Add fabric samples to washing machine, set the washer cycle and time. After that rinsed and dried the samples then line dries the samples. In line dry, hung each sample in vertical direction by clipping it in two corners. Subsequently, the fabric samples were air-dried at room temperature, which was maintained at a maximum of 26°C (79°F) to prevent any heat-induced damage or degradation.

RESULTS

The results of treating untreated polyester fabrics with *A. indica*, *B. monosperma*, and *L. chinensis* demonstrate high applicability, justifying its use in textile finishing due to its potential to provide durable antimicrobial properties and enhance fabric performance.

Table 1. Quantitative analysis test results of treated and untreated polyester sample

	Untreated	*A. indica*	*B. monosperma*	*L. chinensis*	Reduction %
Reading after 22 hours					
1st reading	0	0	0	0	100%
2nd reading	0	0	0	0	100%
3rd reading	0	0	0	0	100%
Reading after 6 days					
1 st reading	4	0	0	0	100%
2nd reading	5	0	0	0	100%
3rd reading	3	0	0	0	100%

There was no microorganism's growth found after 22 hours and even after 6-day interval. Result revealed that polyester fabric showed 89% reduction using *A. indica, B. monosperma* and *L. chinensis* leaves extract antimicrobial finishes as compared to control group. Significant difference (.013) between plant extract and microorganisms' presence on polyester fabric and the effect size was large (η^2=.409).

Table 2. Effect of antimicrobial finish on Microorganisms presences of Polyester Fabric (Univariate Analysis)

Antimicrobial			Plant Extract			
	Df*	SS*	MS*	F	P	η^2
Between-group	3	18.00	6.00	4.615	.013	.409
Within-group	20	26.00	1.30			
Total	23	44.000				

*DF= degree of freedom

*SS= sum of squared differences from the mean

*MS= Mean Square

Table 2 showing significant difference (.013) between plant extract and microorganisms' presence on polyester fabric and the effect size was large (η^2=.409)

A. indica and *B. monosperma* and *L. chinensis* plant extracts had effect on microorganism's presence of polyester fabric as compared to control group.

Table 3. Effect of Antimicrobial finish on Microorganisms presences of polyester fabric

	Plant Name			**Mean Difference (I-J)**		**Std. Error**	**Sig.b**
Microorganisms' presences	Control vs Experimental (*A. indica*)			2.000*		.658	.006
	Control vs Experimental (*B. monosperma*)			2.000*		.658	.006
	Control vs Experime2ntal (*L. chinensis*)			2.000*		.658	.006
	Control Group		*A. indica*		*B. monosperma*		*L. chinensis*
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	2.00	2.28	.00	.00	.00	.00	.00	.00

One way ANOVA showed that the difference in antimicrobial finish between control group (M=2.00, SD=2.28), the first experimental group *A. indica* (M=.00, SD=.00), second experimental group *B. monosperma* (M=.00, SD=.00) and third experimental group *L. chinensis* (M=.00, SD=.00) were statistically significant (F=4.615, p=0.013, η^2=.409).

It revealed that control group scored significantly higher than the experimental groups. However, the three experimental groups (*A. indica*, *B. monosperma* and *L. chinensis)* did not differ significantly. The significant difference between control group and the experimental group is also evident from the big difference in the mean values and remarkable difference in standard deviation (control=2.28, *A. indica*=.00, *B. monosperma* =.00, *L. chinensis*=.00). The hypothesis that antimicrobial finish has no significance effect on polyester fabric was not accepted for *A. indica*, *B. monosperma* and *L. chinensis*. The antimicrobial finish made a significance difference on polyester fabric as microorganism's colony.

Table 4. Colony Characteristics

	Pigments	Microscopy Structure	Surface	Colony Form	Elevation	Margins
Untreated fabric samples						
Polyester	Orange	Gram -ve short thin rods	Smooth	Circular	Raised	Entire
Polyester	Yellow	Gram –ve coccus	Rough	Irregular	Flat	Curled
Polyester	Yellow	Gram –ve Coccus bacilli	Rough	irregular	Flat	Serrate
Polyester	Yellow	Gram –ve coccus	Rough	Irregular	Flat	Serrate
Polyester	Off white	Gram +ve Cocci cluster	Smooth	Circular	Flat	Entire
Polyester	Yellow	Gram –ve coccus	Rough	Irregular	Flat	Serrate
Polyester	Orange	Gram –ve coccus	Rough	Irregular	Flat	Serrate

The readings were taken after 22 hours as mentioned in ASTM 2149 Shake Flask Method and after six days interval to check the effectiveness of antimicrobial finish. There are 8 colonies on untreated polyester fabric. The results showed that the untreated fabric (control group) harbored microorganisms, whereas no colonies were observed on the treated fabrics. The microorganisms present on the untreated fabric were identified as Gram-positive (small thick oval rods, cocci clusters, thick short rods with rounded ends) and Gram-negative (diplococci with short tails, short thin rods, cocci, coccus-bacilli) bacteria, as well as fungi. Based on these findings, a percentage reduction in microorganisms was calculated to assess the efficacy of the treatment

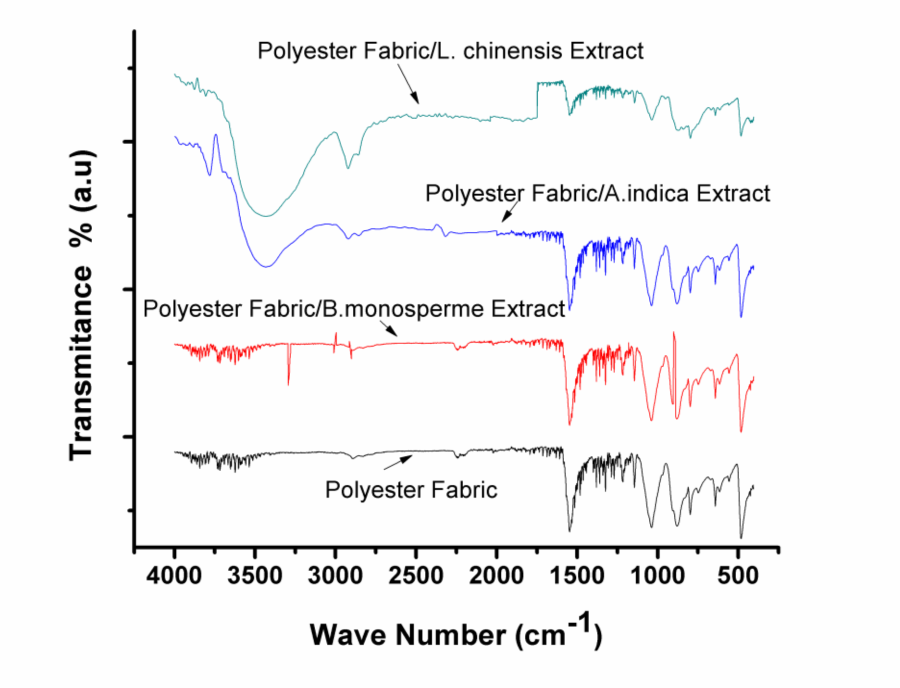

Fig. 1. FTIR Spectra of untreated vs treated polyester fabrics

The FTIR spectrum of polyester fabric is shown in Figure 2. The high peak from 1700 cm^{-1} to 600 cm^{-1} indicates the original signals, such as characteristics spectra of stretching vibration band of C=O at 1730 cm^{-1} and O-C-O stretching vibration band at 1097 cm^{-1} and 1240 cm^{-1}. All these peaks confirm the existence of ester linkage. A broad band region 3435 cm^{-1} which shows the presence of hydroxyl group.

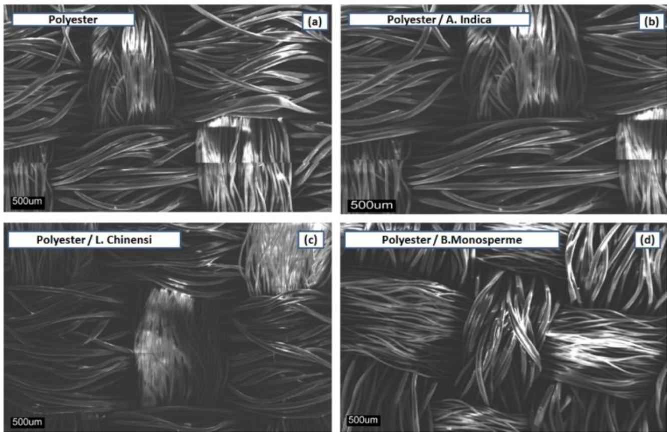

Fig. 2. SEM micrographs of untreated and treated polyester fabric

Fig. 3 portrayed the outcome of treatment of extract on polyester fabric. Figure 3a is the SEM illustration of pure polyester, Figure 3b is *A. indica*, Figure 3c is *L. chinensis*, and Figure 3d is B. monosperma processed polyester fabric. It is revealed that with the dealing of extract on polyester fabric is unaffected for the structure of woven polyester fabric expect the *L. chinensis* in which little bit of breakage has appeared on the surface of the fabric. The treated polyester fabric treated shows presence of finish as compared to untreated fabric. The result indicates that hypothesis is not accepted.

DISCUSSION

In this study, an eco-friendly antimicrobial finish was developed from the leaves of *A. indica, B. monosperma,* and *L. chinensis.* The antimicrobial finish was applied using the pad dry cure method on 100% polyester fabric. The results were discussed in comparison to the untreated fabric (Control Group). The presence of microorganisms was checked on both untreated (Control Group) and treated fabrics. The readings were taken after 22 hours, as referenced in the ASTM 2149 Shake Flask Method, and after six days to test the efficacy of the antimicrobial finish (Emam, 2019). The microorganisms studied were Gram-positive (small thick oval rod, cocci cluster, thick short rods with rounded ends), Gram-negative (diplococci short tail rounded, short thin rod, coccus, coccus bacilli), and fungi, which were observed on the untreated fabric (Darwesh, 2018).

Recent studies have also explored the use of neem oil as an antimicrobial finish. For instance, Guedes (2016) extracted and characterized a surfactant from neem oil (SNO) that showed a yield of approximately 100%. The surfactant demonstrated reasonable soap qualities with a high potential for use as a cleansing agent for textile applications, such as high pH value (10.1), moderate foaming of 1.5 cm, and a critical micelle concentration of almost 0.12 g mL^{-1}. However, the surfactant from neem oil (SNO) showed moderate bactericidal activity against Escherichia coli and bacteriostatic activity against Staphylococcus aureus, both common nosocomial microorganisms (De Smet, 2019). This suggests that the surfactant from neem oil (SNO) has a good potential for use in clinical textile applications due to its soap and bactericidal properties, as it is also biodegradable.

Other studies have explored the use of polyester/aluminum (PET/Al) filters for the high-efficiency simultaneous capture and inactivation of airborne microorganisms that survive on fabric for several days (*E. coli* can survive for 21 days on polyester fiber) (Gressier, 2019). In this study, nonorganic developed on the fibers, and the antimicrobial activity against airborne *E. coli* and *S. epidermidis* improved to around 94.8% and 96.9%, respectively, due to the sustained hydrophobicity and surface roughness of the filter.

Triclosan is a strong candidate for obtaining antibacterial capability against microorganisms for textiles, including clinical applications such as face masks, sterile garments, and wound dressings. Purwar (2009) researched the characterization, antibacterial properties, and durability of triclosan on polyester, polyester/cotton, and cotton surfaces. The pure triclosan and presence of triclosan in solutions were identified by gas chromatography and mass spectrometry chromatograms. In this study, surfaces were homogeneously coated by triclosan, as observed by scanning electron microscope micrographs, and new bands appeared on Fourier transform infrared spectra after treatments. Triclosan showed strong biocidal activity against microorganisms for 3 hours. Although they lost their antibacterial properties after washing, they showed good antibacterial (bactericidal) properties and long-term stability to washes (Gressier, 2019). This suggests that triclosan is a highly effective and durable compound on polyester and cotton surfaces for clinical textile applications.

Additionally, El-Khatib (2012) found that natural antibacterial agents had long-term biocidal effects without being harmful to the environment. Due to their specific targets of action, small molecular antibiotics can cause the growth of microbial resistant species. However, in the case of the currently evaluated antimicrobial agents, destroying microbial cell membranes is reported to be the primary mechanism for preventing microbial growth. Natural antimicrobial finishing compounds (natural and synthetic in origin) have been widely described as one of the main classes of antimicrobial textile finishing agents in this review. Textile antimicrobial compounds derived from natural sources, such as chitosan, cyclodextrins, and natural dyes, were considered environmentally friendly.

CONCLUSION

The study demonstrates the effectiveness of antimicrobial finishes using *A. indica, B. monosperma,* and *L. chinensis* leaves extract on polyester fabric. The results show a significant reduction (89%) in microorganism growth on treated fabrics compared to the control group, with no growth observed even after a 6-day interval. The statistical analysis confirms the significance of the antimicrobial finish, with a large effect size (η^2=.409). The study rejects the hypothesis that antimicrobial finish has no significant effect on polyester fabric, highlighting the potential of these plant extracts as natural antimicrobial agents for textile applications. The findings have important implications for the development of sustainable and eco-friendly antimicrobial finishes for polyester fabrics, reducing the reliance on synthetic chemicals and promoting a safer and healthier environment

ACKNOWLEDGMENTS

The author would like to extend their sincere gratitude to Dr. Tayyab Hussain, Director, Centre of Excellence in Molecular Biology, for his expert guidance and assistance in conducting the antimicrobial experiments. The author also wishes to express their appreciation to Dr. Tanveer Hussain, Rector, National Textile University Faisalabad, for his support and facilitation of antimicrobial finishes on fabric and for providing access to the university's laboratories for testing fabric properties.

CONFLICT OF INTEREST

Authors declare there is no conflict of interest.

REFERENCES

1. Choi DY, Heo KJ, Kang J, An EJ, Jung SH, Lee BU, Jung JH (2018). Washable antimicrobial polyester/aluminum air filter with a high capture efficiency and low pressure drop. J. Hazard. Mater. 351: 29-37.
2. De Smet N (2019). Surfactant from Neem Oil (SNO): A Novel, Eco-Friendly and Multifunctional Agent for Textile Applications. Text. Res. J. 22: 537-547.
3. Emam HE (2019). Antimicrobial cellulosic textiles based on organic compounds. J. Biotech. 9: 1-14.
4. Emam HE, Darwesh O M, Abdelhameed RM (2018). In-growth metal organic framework/synthetic hybrids as antimicrobial fabrics and its toxicity. Colloids Surf B. 165: 219-228.
5. Gressier P, De Smet D, Behary N, Campagne C, Vanneste M (2019). Antibacterial polyester fabrics via diffusion process using active bio-based agents from essential oils. Ind Crops Prod**.** 136: 111-120.

6. Gressier B (2019). Triclosan: A Review of Its Antimicrobial Properties, Applications, and Toxicology.
J. Appl. Microbiol.126: 1221-1235.
7. Guedes RM (2016). Extraction and Characterization of a Surfactant from Neem Oil (SNO) and Its Application in Textile Finishing. J. Text. Appar. Technol. Manag, 6: 1-9.
8. Joshi M, Ali SW, Purwar R, Rajendran S (2009). Ecofriendly antimicrobial finishing of textiles using bioactive agents based on natural products. Ind. J. Fibers Tex. Res. 34: 295-304
9. Maghsoudi S, Nasiri PP, Ebrahimnejad H, Jalali E, Zangiabadi M (2021). Decoration of cotton fiber with biosynthesized Ag/ZnO nanocomposite for durable antibacterial textile. J. Nat. Fibers. 52: 1-11.
10. Martirosyan I, Pakholiuk O, Semak B, Lubenets V, Peredriy O (2019). Investigation of wear resistance of cotton-polyester fabric with antimicrobial treatment. In: Grabchenko's International Conference on Advanced Manufacturing Processes. Springer, Cham. 433-441.
11. Morais DS, Guedes RM, Lopes MA (2016). Antimicrobial approaches for textiles: from research to market. Mater. Res. 9: 498.
12. Orhan M (2020). Triclosan applications for biocidal functionalization of polyester and cotton surfaces. Eng. Fibers Fabr. 15: 1-11.
13. Prabhu K H, Teli MD (2011). Eco-dyeing using *Tamarindus indica* L. seed coat tannin as a natural mordant for textiles with antibacterial activity.J. Saudi Chem. Soc. 12: 753-759.
14. Rajput A, Ramachandran M, Gotmare VD, Raichurkar PP (2017). Recent bioactive materials for development of eco-friendly dippers: an overview. J. Pharm. Res. 9: 1844-1848.
15. Raja ASM, Thilagavathi C (2011). Influence of enzyme and mordant treatments on the antimicrobial efficacy of natural dyes on wool materials. Asian J. Text. 1: 138-144.
16. Sauperl O (2016). Textiles for protection against microorganisms. AIP Conf. 1727: 20021.
17. Shibly MMH, Hossain MF, Rahman M, Nur MG (2019). Development of cost-effective menstrual absorbent pad with eco-friendly antimicrobial finish. Eur. Sci. J. 15: 438-445.
18. Siqueira de Azevedo C, Ladchumananandasivam R, Rossi CG, Silva RKda, Camboim Wda, S, Zille A, Padrão J, Silva KKde OS (2021). Characterization of a natural surfactant from an essential oil from neem (*Azadirachta indica A. Juss*) for textile industry applications. Text. Res. J. 91: 1241-1253.

19. Zanoaga M, Tanasa F (2014). Antimicrobial reagents as functional finishing for textiles intended for biomedical applications. J. Org. Chem. 9: 14-32.