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# Herbal-based antimicrobial textiles: efficacy of *Datura metel* extract on cotton and linen

Jesica Roshima[1] & Aravin Prince Periyasamy[2,a]
[1]VIT Fashion Institute of Technology, VIT, Chennai 600 127, India
[2]Department of Material Engineering, Technical University of Liberec, Liberec 461 17, Czech Republic

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This study investigates the application of natural plant extracts (*Datura metel*) to cellulose fabrics (linen and cotton) using microencapsulation, with the aim of improving the durability and bioactivity of these natural materials for health benefit applications. The fabrics have been treated with microencapsulated plant extracts, and their surface chemistry has been analysed using FTIR, while SEM is employed to assess microcapsule deposition. The antibacterial properties of the fabrics have been evaluated under different washing conditions to determine their durability. Results show successful encapsulation and deposition of the plant extracts, with the treated fabrics retaining their antibacterial efficacy even after washing. This indicates improved durability, making them suitable for medical applications. The research demonstrates the potential of herbal-based materials to enhance the functionality and longevity of medical textiles.

**Keywords:** Antimicrobial activity, Biomaterials, Cellulose, Microencapsulation, Sustainable textile

## 1 Introduction

Medical textiles, positioned at the intersection of (bio) polymer chemistry, textile technology and medical science, signify the forefront of technical textile advancements, showcasing innovations that extend well beyond conventional boundaries[1]. The first generative biomaterial is a deliberately crafted substance that is pharmacologically inert, intended for insertion into or integration with a living organism[2]. The utilisation of biomedical textiles is pervasive in today's landscape, often surpassing general awareness. Hence, possessing comprehensive knowledge about these materials is crucial. Such understanding contributes significantly to enhanced patient care management by optimising their utilisation[3].

The medical sector relies heavily on a diverse array of textiles and bio-based materials sourced from animals, minerals, and plants[4–6]. These bio-based medical textiles typically exhibit unique characteristics, including biocompatibility, biodegradability, and morphological adaptability as compared to synthetic ones[7]. The discovery of the interconnectedness between renewable natural resources and biomaterials within the realm of sustainable biomaterials presents an auspicious opportunity for the advancement of fresh sustainable development strategies in the coming years[8]. This linkage underscores the potential for leveraging renewable resources in the creation of biomaterials, thereby fostering a more sustainable approach to material production and consumption and fulfil the various sustainable development goals (SDGs)[9–11]. By tapping into this synergy, there's a promising trajectory towards the successful implementation of innovative sustainable practices, offering a pathway towards a more environmentally conscious and resilient future[12]. Moreover, these biomaterials can serve as a source of inspiration for the development of drug delivery systems[13]. Understanding sustainable biomaterials requires a holistic view of their life cycle. This entails evaluating their properties, longevity, and environmental impact from production to disposal. By considering each stage, including production, processing, degradation, recycling, or disposal, we can identify biomaterials that align with sustainability principles[14]. These materials not only exhibit desirable properties but also minimise environmental harm, promoting responsible resource management[15].

Biomaterials, which are typically referred to as substances utilised in medical devices, have been around since the dawn of time, but only recently have they become much more sophisticated[16]. Natural biomaterials made from living organisms that are

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[a]Corresponding author.
E-mail: aravinprincep@gmail.com

renewable, including plants, animals, and microorganisms, have a wide range of distinctive yet complicated elements, microstructures, and physiological characteristics[17,18]. Therefore, this research concentrates on creating environmentally friendly cellulosic materials incorporated with herbal extracts using microencapsulation techniques. Textile functionalities can be enhanced through the application of diverse encapsulated materials derived from natural sources[19]. Microencapsulation presents numerous prospects for enhancing properties or introducing novel functionalities in the production of textiles, garments, and apparel, thereby expanding their applicability and augmenting their market value. Previous literature reviews in both scientific and patent domains have extensively explored the applications of microencapsulation in textiles[20]. However, a research gap remains in exploring the potential of natural-based biomaterials for medical applications, particularly in terms of durability, stability, and controlled degradation.

In this study, herbal extracts from *Datura metel*, a plant recognised for its biocompatibility and biodegradability[21], were microencapsulated and applied to two widely used cellulosic substrates, cotton and linen. These fabrics are traditionally employed in medical products, particularly wound dressings, owing to their absorbency[22]. Recent findings suggest that cotton and linen not only enhance wound healing but also inhibit microbial growth[23]. To our knowledge, this is the first report on the microencapsulation of *D. metel* extracts for imparting biofunctional properties to cotton and linen textiles.

## 2. Materials and Methods

### 2.1 Materials

Woven cotton and linen fabrics with a thread count of 80 Ne were used in this study. The fabrics were scoured and bleached, achieving areal densities of 72.5 g.m$^{-2}$ and 112.28 g.m$^{-2}$, and thicknesses of 1.54 mm and 3.28 mm, respectively. *D. metel* plants [Fig. 1 (a)] were procured from Tuticorin, India, and shadow dried at 37- 40 °C [Fig. 1 (b)] to reduce the moisture content to below 14 %. The dried herbs were ground into small units, ranging from coarse fragments to fine powders [Fig. 1 (c)] and stored in airtight containers for further processing. Proper drying is crucial to prevent contamination of significant compounds. Fine ground herbal powders were subsequently placed in porous bags or thimbles for solvent extraction [Fig. 1 (d)].

### 2.2 Extraction of Bioactive Compounds

The bioactive compounds were extracted using a Soxhlet apparatus. Finely ground *D. metel* powder was placed in a porous bag or thimble and extracted with ethanol. 20 g of each powder was mixed with 100 mL of ethanol and kept at room temperature (~ 25 °C) for 6 h. The solvent was then evaporated, and the concentrated extracts were collected and stored in sterile containers.

### 2.3 Antimicrobial Activity of Extracts

The antibacterial and antifungal activities of *D. metel* extract were evaluated using the AATCC147 and AATCC30 well diffusion methods, respectively. For antibacterial testing, four Gram-positive strains (*Staphylococcus aureus, Klebsiella sp., Pseudomonas sp., Bacillus sp.*) and four Gram-negative strains (*Escherichia coli, S. epidermidis, Citrobacter sp., Micrococcus sp.*) were used. Sterile nutrient agar plates were swabbed with bacterial cultures, and 50 µL of the extract (dissolved in 5 % DMSO) was added to each well. Plates were incubated at 37 °C for 24–48 h, and the zones of inhibition (ZoI) were measured.

For antifungal testing, five fungal strains (*Candida albicans, C. tropicalis, C. krusei, Aspergillus niger, Trichoderma sp.*) were cultured on sterile potato dextrose agar (PDA). Extracts were introduced into wells, and the antifungal effect was determined by ZoI after incubation at 37 °C for 24–48 h.

Fig. 1 — Solvent extraction of *D. metel* for textile finishing: (a) fresh plant, (b) dried leaves, (c) herbal powder, and (d) solvent extract

### 2.4 Characterisation of Herbal Extracts

#### *2.4.1 GC-MS Analysis*

Gas chromatography–mass spectrometry (GC–MS) was used to identify the components of the ethanolic extract of *D. metel* leaves. A Hewlett-Packard 5890 gas chromatograph coupled with a Hewlett-Packard 5989B mass spectrometer was employed.

#### *2.4.2 FTIR Analysis*

Fourier Transform Infrared (FTIR) spectroscopy was performed using a Nicolet iS10 spectrometer equipped with a ZnSe ATR crystal. Spectra were recorded in the range 4000–500 $\mathrm{cm}^{-1}$. To prevent atmospheric moisture interference, the instrument was continuously purged with dry air.

#### *2.4.3 Microencapsulation Preparatory Process*

The *D. metel* extract was microencapsulated using sodium alginate as the wall material. Sodium alginate was dissolved in sterile distilled water to form a homogeneous solution. Herbal extracts were prepared at concentrations of 1 %, 3 %, and 5 % relative to the core material. Each concentration was thoroughly mixed with 10 g of sodium alginate solution to form a viscous dispersion, which was dropped into a 0.5 mL $CaCl_2$ solution under aseptic conditions. Ionic gelation of alginate in $CaCl_2$ resulted in the formation of microcapsules. These were retained in the solution for 15 min to ensure complete crosslinking, decanted, washed with isopropyl alcohol, and dried at 45 °C for 12 h.

#### *2.4.4 Application of Microcapsules to Fabrics*

Cotton and linen fabrics were finished with *D. metel* microcapsules at 1 %, 3 %, and 5 % concentrations. Microcapsules were dispersed with citric acid, which acted as a crosslinking agent and catalyst for esterification. Fabrics were immersed in an 8 % citric acid solution for 30 min at 50 °C, then air-dried at room temperature (~25 °C). The same procedure was applied to both cotton and linen.

### 2.5 Antimicrobial Test for Microencapsulated Fabrics

#### *2.5.1 Quantitative Test (Antibacterial)*

The antibacterial activity of treated fabrics was assessed against *S. aureus* and *E. coli* using the AATCC 100 method. Fabric swatches were inoculated with bacterial suspensions in nutrient broth and incubated at 37 ± 2 °C for 18 h. Bacterial populations were determined by plating aliquots after incubation. The reduction percentage was calculated using Eq. 1:

$$R(\%) = \frac{A - B}{A} \times 100 \qquad \ldots (1)$$

where $A$ is the initial bacterial count; and $B$, final count after 18 h.

#### *2.5.2 Qualitative Test (Antibacterial)*

The AATCC 147 method was used to evaluate the antibacterial properties of microencapsulated fabrics. Test specimens were cut into pieces and placed on agar plates inoculated with *S. aureus* and *E. coli* and incubated at 37 °C for 18–24 h. ZoI were recorded to confirm antibacterial efficacy.

#### *2.5.3 Qualitative Test (Antifungal)*

The antifungal activity of fabrics treated with 1 %, 3 %, and 5 % microcapsules was tested against *C. albicans* and *C. tropicalis* using the AATCC 30 method. Sterile PDA plates were inoculated with fungal cultures, and 50 mm fabric samples were placed on the surface. After incubation at 37 °C for 24–48 h, ZoI were measured.

### 2.6 SEM Analysis

Scanning Electron Microscopy (SEM) was performed to observe the surface morphology of microencapsulated fabrics. A pre-cantered tungsten hairpin filament electron gun was operated at 0.5–30 kV for imaging.

### 2.7 Wash Durability of Microencapsulated Fabrics

The wash durability of fabrics treated with 5 % *D. metel* microcapsules was evaluated following ISO 6330–1984 standards. Fabrics were washed at 40 °C using neutral pH detergent and subjected to antibacterial and antifungal tests after the 2nd, 10th, 18th, and 20th wash cycles. Antibacterial durability was tested using the EN 14119 method with *S. aureus* and *E. coli*. Fabric specimens (20 mm) were incubated on bacteriostasis agar plates at 37 °C for 24 h. Antifungal durability was tested using the AATCC 30 method with *C. albicans* and *C. tropicalis*. Treated fabrics were placed on inoculated PDA plates, incubated at 37 °C for 24–48 h, and ZoI were recorded after each wash cycle.

## 3 Results and Discussion

### 3.1 FTIR Characterisation

The FTIR spectrum of *D. metel* leaf extract confirms the presence of characteristic functional groups (Fig. 2). A distinct band at 3650 $\mathrm{cm}^{-1}$ corresponds to the O–H stretching vibration of the alcohol (– OH) group. The peak at 2955 cm$^{-1}$ corresponds to the stretching of C-H bonds in alkyl groups, while a prominent peak at 1428 cm$^{-1}$ reflects the stretching vibration of C = C bonds of carboxylic groups. The peak at 1718 cm$^{-1}$ indicates the occurrence of the C-N stretching vibration in aliphatic amines[21]. Additionally, the peaks at 1310 and 1351 cm$^{-1}$ correspond to the C-C stretching vibration in aromatics and the vibration of nitro compounds, namely the C-N stretching vibration in aromatic amines. The observed peaks at 1105 and 1068 cm$^{-1}$ can be attributed to the C-N bond of aliphatic amines. The presence of C–Cl stretch alkyl halides, C-H bend alkanes, and C-I stretches aliphatic iodo compounds is indicated by the peaks observed at 730, 776, and 639 cm$^{-1}$. These spectral features confirm the presence of bioactive constituents, while FTIR further serves as a tool to monitor potential structural changes, thereby ensuring the chemical stability of the encapsulated compounds during processing.

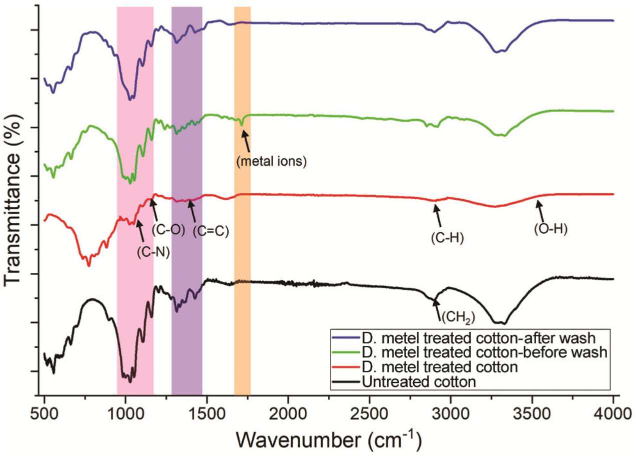

Fig. 2 — FTIR spectra of *D. metel* extract, untreated cotton and treated cotton (before and after washing)

### 3.2 Surface Morphology Analysis

SEM analysis reveals that the microencapsulated cotton and linen fabrics exhibit spherical microcapsules, with sizes ranging from 13 to 84 µm [(Fig. 3 (a)]. In contrast, *D. metel* extract alone shows a narrower particle size distribution of 13.6–30.2 µm, with a mean size of 23.4 µm [(Fig. 3 (b)]. The findings of this study indicate that the microcapsules produced exhibit a consistent size distribution and possess a nearly spherical shape, characterised by a smooth surface. Untreated fabrics [(Fig. 3 (c)] show plain fibrous surfaces, while microencapsulated fabrics [(Fig. 3 (d)] exhibit a dense and even distribution of microcapsules across the fibres. It is worth mentioning that the microcapsules demonstrate a consistent coating throughout the fibrous structure and ensure the functionalisation is uniform throughout the fabric materials, with a slightly elevated concentration observed in the interstices. The application of *D. metel* leaves extract through microencapsulation results in a noticeable deposition of microcapsules on the surface of the fabric. Higher magnification images [Fig. 3 (e–f)] confirm the effective attachment of microcapsules to fibres. After simulated washing cycles (5 and 10

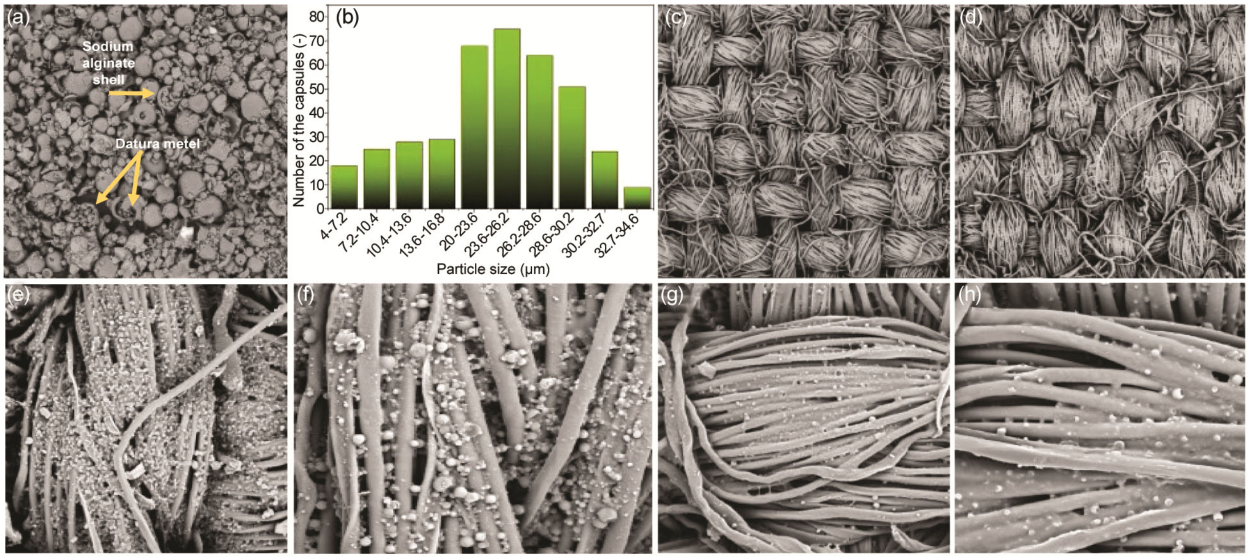

Fig. 3 — SEM images of (a) *D. metel* microcapsules, (b) particle size distribution of microcapsules, (c, d) microencapsulated fabric, (e) fibre surface with adhered microcapsules, (f) higher magnification of fibre surface, and washed fabrics after (g) 5 wash cycles, and (h) 10 wash cycles

washes), the fabrics retain noticeable deposits of microcapsules [Fig. 3 (g–h)], demonstrating durability and persistence of treatment.

### 3.3 Antimicrobial Activity

The antimicrobial potential of *D. metel* extract is assessed against Gram-negative and Gram-positive (+ve) bacteria, as well as fungi (Table 1). The extract exhibits broad-spectrum antibacterial efficacy, with inhibition zones ranging from 13 to 21 mm. Notably, the highest activity is observed against *E. coli* (21 mm), *Klebsiella sp.* (20 mm), and *Aspergillus niger* (20 mm). The extract also demonstrates significant antifungal activity against *Candida albicans* and *Trichoderma sp.* (both 20 mm). This suggests a robust antibacterial activity in the *D. metel* herbal extract, demonstrating its suitability as a bioactive agent for textile finishing.

### 3.4 GC-MS Analysis

GC–MS analysis identifies multiple bioactive compounds in the ethanolic extract of *D. metel* (Fig. 4; Table 2). The initial peak is identified as 2-(dimethylamino)-3-phenylbenzo[b]thiophene, a thiol-containing molecule commonly used in pharmaceutical production. This compound is notable for its bioactive properties, potentially contributing to antimicrobial effects due to the presence of the thiophene ring, which is known to interact with biological systems and inhibit microbial growth[24]. The second peak is identified as 2-(2-Pyridyl)-3-(trimethylsilyl)-6, 7-dihydro- 5H-cyclopenta [b]pyridine. The other peaks are identified as several chemicals, namely 2-Amino-3-phenyl-6-nitroindole, 4-Ethyl-2-allyl-1-methoxynaphthalene-3-carbaldehyde, 5-Iodo-2-methyl-4-nitroimidazole, 1-nitrophenanthro [4,5-bcd]thiophene, and 3-methoxy-4- [(trimethylsilyl)oxy].

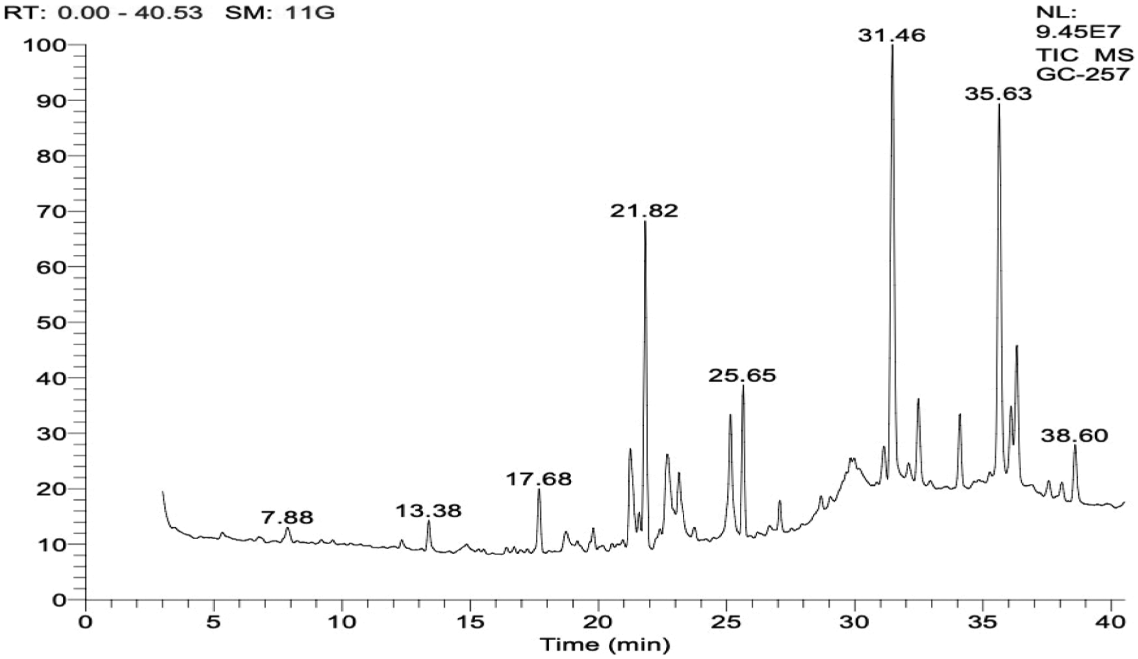

Fig. 4 — GC-MS chromatogram of *D. metal* extract

Table 1 — Antimicrobial activity of *D. metel* extract using various methods (zone of inhibition, mm)

| Bacterial strains | | | | | | | | Fungal strains | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gram +ve bacteria | | | | Gram -ve bacteria | | | | | | | | |
| *S. aureus* | *S. epidermidis* | *Micrococcus* sp. | *Bacillus* sp. | *E. coli* | *Klebsiella* sp. | *Citrobacter* sp. | *Pseudomonas* sp. | *C. albicans* | *C. tropicalis* | *C. krusei* | *Aspergillus niger* | *Trichoderma* sp. |
| 20 | 13 | 14 | 16 | 21 | 20 | 19 | 19 | 18 | 17 | 15 | 20 | 20 |

Table 2 — GC-MS profile of *D. metel* extract

| SI | RSI | Compound | Mol. formula | Probability | Mol. weight | Area, % |
|---|---|---|---|---|---|---|
| 740 | 949 | Dodecane, CAS | $C_{12}H_{26}$ | 45.13 | 170 | 0.77 |
| 917 | 919 | Dodecanoic Acid, Methyl Ester | $C_{13}H_{26}O_2$ | 62.68 | 214 | 1.05 |
| 840 | 962 | Tetradecanoic acid, methyl Ester, CAS | $C_{15}H_{30}O_2$ | 48.65 | 242 | 2.14 |
| 956 | 956 | Hexadecanoic acid, methyl ester | $C_{17}H_{34}O_2$ | 65.00 | 270 | 11.07 |
| 936 | 936 | Methyl stearate | $C_{19}H_{38}O_2$ | 58.03 | 298 | 4.14 |
| 950 | 950 | 1,2-Benzenedicarboxylic acid, Mono, 2-ethylhexyl ester | $C_{16}H_{22}O4$ | 37.68 | 278 | 19.02 |
| 826 | 828 | 13-Docosenamide, Z | $C22H_{43}NO$ | 59.01 | 337 | 14.19 |
| 904 | 924 | Hexatriacontane, CAS | $C36H_{74}$ | 10.17 | 506 | 2.19 |

*Note: SI: Match Factor; RSI: Reverse Match Factor*

Table 3 — Antimicrobial test for cotton and linen fabrics with different concentrations of *D. metel* extract (zone of inhibition, mm)

| Antimicrobe | *S. aureus* | | | *E. coli* | | | *S. aureus* | | | *E. coli* | | | *C. albicans* | | | *C. tropicalis* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *D. metel* conc., % | 1 | 3 | 5 | 1 | 3 | 5 | 1 | 3 | 5 | 1 | 3 | 5 | 1 | 3 | 5 | 1 | 3 | 5 |
| | Quantitative method (AATCC100) | | | | | | Qualitative method (AATCC147) | | | | | | Qualitative method (AATCC30) | | | | | |
| Control | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cotton | 72 | 81 | 95 | 71 | 82 | 91 | 30 | 33 | 37 | 29 | 32 | 36 | 52 | 55 | 64 | 53 | 59 | 65 |
| Linen | 74 | 88 | 93 | 71 | 86 | 95 | 28 | 32 | 35 | 30 | 33 | 36 | 53 | 55 | 65 | 55 | 56 | 62 |

**Percentage of core material (i.e. herb) was taken based on the sodium alginate (i.e.* wall material).

Table 4 — Antimicrobial activity of cotton and linen fabrics treated with *D. metel* extract across different wash cycles (zone of inhibition, mm)

| Antimicrobial agent | *S. aureus* | | | *E. coli* | | | *C. albicans* | | | *C. tropicalis* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. of wash | 2 | 10 | 20 | 2 | 10 | 20 | 2 | 10 | 20 | 2 | 10 | 20 |
| Untreated cotton | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil |
| Untreated linen | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil |
| Treated cotton | 30 | 20 | 10 | 31 | 19 | 09 | 60 | 56 | 18 | 62 | 57 | 10 |
| Treated linen | 30 | 21 | 08 | 30 | 18 | 07 | 61 | 56 | 19 | 60 | 56 | 07 |

The compounds mentioned are: benzaldehyde-O-methyloxime, benzaldehyde, 3-methoxy-4-[(trimethyl-silyl)oxy], O-methyloxime (CAS), 2, 6-bis(methy-lthio)-4- (2-thienyl)pyridine, and 6-amino-1-(2-carboxy-3-methoxy)phenyl. Significantly, a number of these discovered phytocompounds have antibacterial characteristics, emphasising their potential for medicinal use. Plant-derived antimicrobials, renowned for their effectiveness and comparatively limited adverse effects, hold great potential in the realm of medicine. These antimicrobial components in the extract of *D. metel* leaves highlight its potential as a significant natural resource with antibacterial characteristics.

### 3.5 Antimicrobial Activity of Microencapsulated Fabrics

Microencapsulated cotton and linen fabrics, treated with 1 %, 3 %, and 5 % concentrations of *D. metel* extract, show dose-dependent antimicrobial activity (Table 3). At 5 %, the fabrics achieve the highest inhibition, with *S. aureus* and *E. coli* inhibition zones reaching 95 % and 91 %, respectively. Similarly, antifungal activity is maximised at 5 %, with inhibition zones against *C. albicans* and *C. tropicalis* exceeding 60 mm. Both qualitative (AATCC 147, AATCC 30) and quantitative (AATCC 100) tests confirm that encapsulation enhances the durability and uniformity of antimicrobial efficacy. The results consistently demonstrate that a 5 % concentration of *D. metel* provides the most effective antibacterial and antifungal protection.

### 3.6 Wash Durability

The antibacterial durability of microencapsulated fabrics is evaluated across 2, 10, and 20 wash cycles (Table 4). Although the inhibition zones gradually decrease with repeated washing, bioactivity remains detectable even after 20 cycles. For cotton, the inhibition zone against *S. aureus* and *E. coli* decreases from 30 mm (2nd wash) to 10 mm (20th wash), and from 31 mm (2nd wash) to 9 mm (20nd wash), respectively. Linen shows a similar trend, decreasing from 30 mm to 8 mm. These findings confirm that microencapsulation prolongs the functional lifetime of treated fabrics under domestic laundering conditions. This demonstrates that microencapsulation treatment is effective and durable throughout various wash cycles.

The antifungal durability of treated fabrics is similarly assessed (Table 4). The fabrics retain strong antifungal activity after 2 and 10 washes, with inhibition zones of 56–62 mm. After 20 washes, activity decreases but remains detectable, with zones of 7–19 mm. The results indicate that fungal resistance is more persistent than bacterial resistance under repeated laundering, suggesting robust adherence of *D. metel* microcapsules to fabric fibres.

## 4 Conclusion

This study demonstrates that *D. metel* leaf extract is a promising source of bioactive compounds with strong antibacterial and antifungal properties. FTIR and GC–MS analyses confirm the presence of phenolic, alkaloid, ester, and amide groups, which contribute to the extract's antimicrobial efficacy. Microencapsulation of the extract on cotton and linen fabrics results in uniform deposition of spherical microcapsules, as confirmed by SEM analysis, and enhances the durability of functional performance. The treated fabrics exhibit significant inhibition against both Gram-positive and Gram-negative bacteria, as well as pathogenic fungi, with activity increasing in a dose-dependent manner. Wash durability tests further show that antimicrobial properties persist after multiple laundering cycles, although a gradual reduction is observed with higher wash numbers. The findings establish that *D. metel* extract can be effectively employed for the development of antimicrobial textiles. The incorporation of herbal microcapsules not only improves fabric functionality but also provides a sustainable alternative to synthetic finishes, with potential applications in healthcare, hygiene, and protective clothing.

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