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Development of a novel bacterial transport swab using bioscoured Himalayan *Urtica parviflora* fibres

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The Himalayan stinging nettle (*Urtica parviflora*) remains an underutilised natural resource in Sikkim, with limited research exploring its fibre potential. This study introduces a novel application of nettle bast fibres for the development of bacterial transport swabs — a first of its kind globally. Nettle fibres are extracted through retting and enzymatic bioscouring, followed by detailed characterisation using SEM, FTIR and TGA analyses. Swabs fabricated from these fibres are evaluated for absorption capacity and validated through qualitative (roll-plate) and quantitative (swab elution) bacterial recovery tests against standard cotton and viscose swabs. The results reveal that nettle fibre swabs perform comparably to cotton and viscose in terms of bacterial recovery and absorption efficiency. Additionally, nettle offers advantages of renewability, biodegradability, and low production cost. The findings highlight nettle fibre as a promising sustainable alternative for microbiological transport swabs, combining functional performance with environmental and economic benefits.

Keywords: Absorption capacity, Bioscouring, Nettle fibre, Swab validation, Transport swab

1 Introduction

One of the commonly used single-use medical devices for transporting, transferring and applying samples in a clinical microbiology laboratory is a sterile swab[1]. The utilisation of swabs extends not only to isolating bacteria, viruses, fungi, DNA, and RNA but also includes a wide range of applications such as point-of-care testing, forensic testing, surface sampling, and cleaning[2]. Various types of medical swabs have differences in tip materials and designs, with plastic or wooden shafts that are either whole or scored, depending upon sampling requirements. An ideal microbiological transport swab for bacterial culturing should be readily available, inexpensive, sterile, swift, and have large tip sizes for high-volume soakage. Nowadays, ready-to-use sterile synthetic swabs replace cotton/viscose swabs as they are presumably more reliable for recovering DNA/RNA and delicate organisms[1,3].

A clinical Microbiology laboratory generates a lot of biohazardous infectious waste daily. Although the quantity of used medical swab waste is a small fraction compared to general plastic and biomaterial wastes, in the long run, they will also contribute to a significant burden. Besides, medical swab wastes cannot be recycled or reused when collecting hazardous biological samples. Nonetheless, the end-of-life fate of a used swab in biomedical waste management is pre-treatment (by autoclaving) and disposal (by incineration or plasma pyrolysis), contributing to further pollution as a necessary evil. The innocuous cotton/viscose swabs are also not as eco-friendly as they are perceived to be. Likewise, various synthetic (polyester, rayon, nylon, foam) swabs preferred over cotton swabs are not sustainable. There is a dependence on the overuse of inexpensive swabs, and just like petroleum-based semi/synthetic materials, non-organic cotton offers low justifiable solutions to problems arising from its unsustainable production and final disposal. This study aimed to utilise nettle fibres for biomedical applications like swab-making. Nettle fibres provided a more sustainable, inexpensive and environment-friendly option[4-6].

Nettle is an emerging crop with multipurpose uses; it has few pests and diseases, grows well in overly fertilised soil, and requires less weed control as soon as crop cover develops[7,8]. Before the popularity of cotton grew, nettle fibres used as textiles were well documented in the chapters of textile histories of Europe, the Americas and the Asian regions, as the plant is native to most continents[4-8]. In literature, the two genera of the family Urticaceae, viz. *Girardinia*

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species and *Urtica* species are interchangeably called the Nettle plant. Most European and American literature describes the *Urtica* species used for textile purposes, whereas Himalayan history describes *Girardinia diversifolia* and *Urtica* species usage as textile fibres[4-9]. Similarly, in Sikkim, the *Urtica* nettle is often used for textile, medicinal and consumption purposes, and the Lepcha tribe primarily uses *Girardinia diversifolia* bark fibres for textiles[10].

Most nettle fibre research is on developing and refining the processes of fibre extraction for textiles, value-added products, and biocomposites[4]. Despite this, using this sustainable fibre to make the ubiquitous single-use culture swab has not been done, and there is scant literature on the potential uses of *Urtica parviflora* fibres for biomedical applications. The nettle plant chosen in this study is from a renewable source, is easily accessible, and is a traditionally known textile material in Sikkim. The *Urtica parviflora* fibres in this study are cellulosic fibres having physical attributes, absorbency, and the ability to wrap in a wooden swab shaft tip efficiently without unravelling, similar to cotton. Studies have shown that nettle plants have long fibres[5,6,11], ideal for making fibre-wrapped swabs[2]. Accordingly, this experimental research study intends to utilise enzyme-bioscoured *Urtica parviflora* fibre (natural fibre) as an alternative fibre to cotton (natural fibre) and viscose (manufactured fibre) for swab making. Validation assessments were made by enumerating bacterial recovery with different swabbing methodologies and comparing the effectiveness of the nettle swab as a transport swab with commercially available cotton and viscose transport swabs.

2 Materials and Methods

The sequential workflow of the study is illustrated in Fig. 1.

2.1 Nettle Fibre Extraction and Processing

Wild nettle (*Urtica parviflora* Roxb.) was harvested from the 5th mile (27.32 °C N, 88.59 °C E), Tadong, Sikkim, India, during September–November, corresponding to the late flowering and fruiting stage when fibre quality is optimal. Over-mature or excessively lignified plants were excluded, as higher lignification reduces cellulose content[4,12]. The species

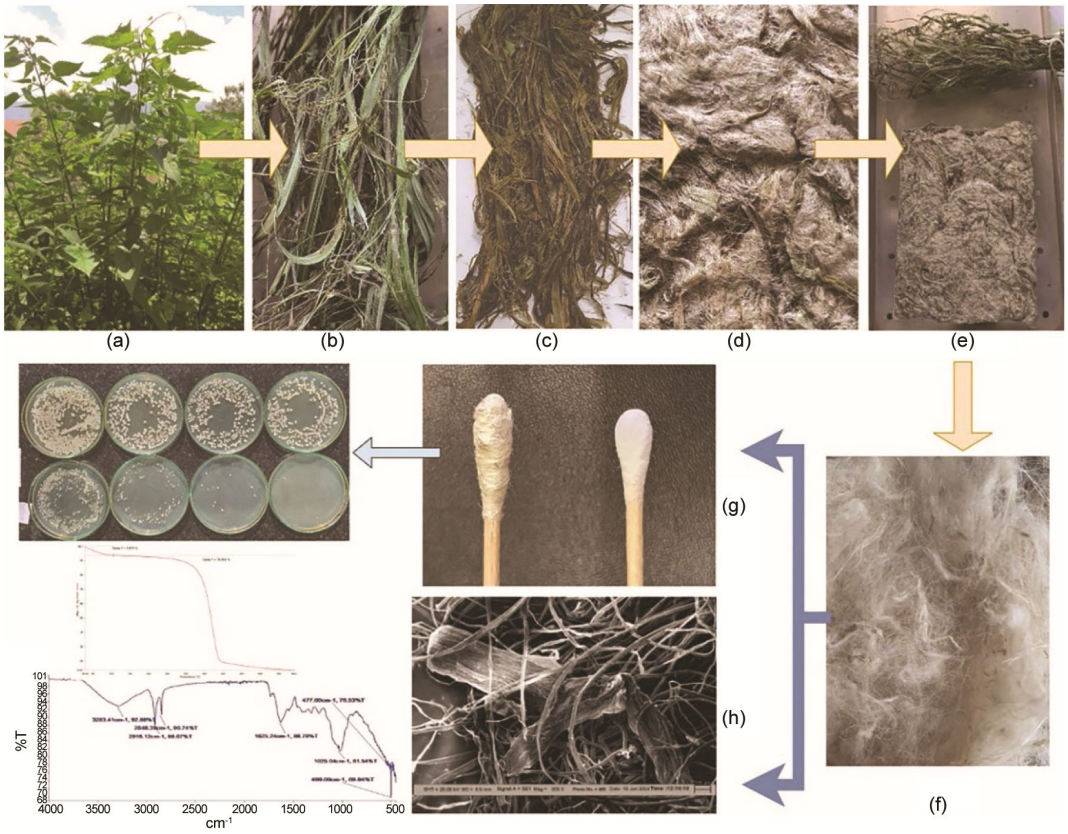

Fig. 1 — Sequential steps in nettle fibre preparation (a) harvesting, (b) decortication, (c) degumming of dried bark by water retting, (d) enzymatic bioscouring, (e) drying of washed fibres, (f) fibre carding and forming wool, (g) nettle swabs making and microbiological testing, and (h) fibre characterisation

was taxonomically identified by the Botanical Survey of India (BSI), Sikkim Himalayan Regional Centre, Sikkim vide letter no: SHRC-5/02/2023-24/Tech./049 dated 21/04/2023. Harvested stalks were decorticated, air-dried, and subjected to microbiological retting for 5–6 days at ambient temperature (10–23 °C) using a *Bacillus* consortium (0.25 %, v/v) isolated from soil enriched with fruit and vegetable waste. Retting released bast fibres, which were washed and dried.

Enzymatic bioscouring was performed using the purified crude pectinase (3 %) and xylanase (1 %) enzymes in PBS (pH 6–7) containing 2 % wetting agent (Polysorbate-80 and Polysorbate-20) and 1 % EDTA at 50 °C for 45–50 min at a material-to-liquor ratio of 1:15. Fibres were washed, air-dried, and carded into uniform rolags. This experiment is a modification of the bioscouring method described by Singh *et al.*[13].

2.2 Nettle Fibre Characterisation

The ultrastructure of the dried bark (untreated) and crude enzyme-treated (bioscoured) nettle fibre was analysed using SEM (Nishka Research Laboratory, Hyderabad and IIT-Delhi, respectively). FTIR and TGA were performed to determine the chemical composition and thermal degradation of the bioscoured nettle fibre (Nishka Research Laboratory, Hyderabad).

2.2.1 Scanning Electron Microscopy (SEM)

Dried bark (untreated) and bioscoured nettle fibres were mounted on aluminium stubs with carbon tape and sputter-coated with gold (20-30 nm thickness). SEM imaging was performed using ZEISS EVO 50 and Hitachi S-3700N microscopes of dried decorticated bark and bioscoured nettle fibres.

2.2.2 Fourier Transform Infrared (FTIR)

FTIR was used to determine the functional groups in the untreated and treated nettle fibres. FTIR spectra of untreated and bioscoured nettle fibres were recorded using a Perkin Elmer Spectrum Two spectrometer in the 4000–500 cm^{-1} range (32 scans at 4 cm^{-1} resolution). The spectra were analysed using spectroscopic tools[14].

2.2.3 Thermogravimetric Analysis (TGA)

TGA was done using a Perkin-Elmer TGA-4000 analyser. For each measurement, about 9-10 mg of fibres in aluminium crucibles were heated from 30 °C-600 °C at 10 °C/min in an inert nitrogen atmosphere.

2.3 Preparation of Nettle Swabs

Nettle swabs were fabricated in-house (Fig. 2), while sterile cotton and viscose swabs were procured from HiMedia, India. A pledget (3.5–4 × 1.3–1.5 cm) of carded nettle fibres was manually wrapped around

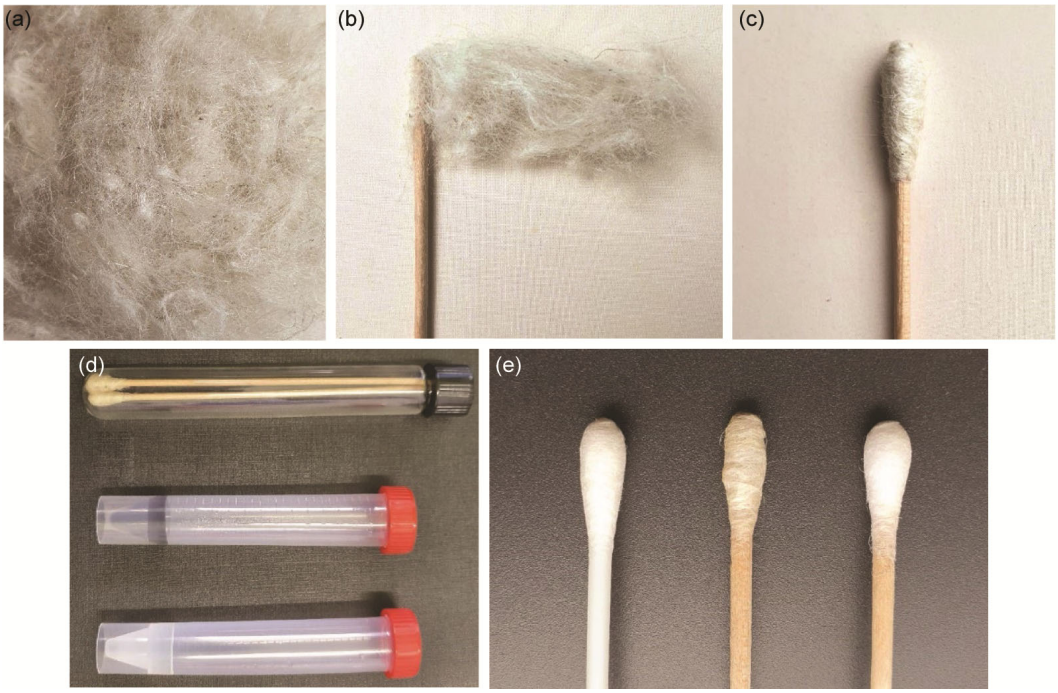

Fig. 2 — Swab preparation process (a) nettle fibre wool, (b-c) manual nettle swab making, (d) swab with transport medium, and (e) viscose (left), nettle (middle) and cotton (right) swabs

Table 1 — Dimensional parameters of nettle, cotton and viscose fibre swabs

Swab type	Tip length, cm	Tip diameter, cm	Length of entire swab, cm	Weight, g
Nettle	1.41 ± 0.06	0.5 ± 0.007	15.19 ± 0.02	0.4 ± 0.03
Cotton	1.09 ± 0.05	0.49 ± 0.004	15.18 ± 0.02	0.42 ± 0.03
Viscose	1.4 ± 0.02	0.49 ± 0.01	15.17 ± 0.03	0.62 ± 0.01

**Data represent mean ± SD (n = 5)*

one end of a sterile wooden dowel. Swab dimensions are given in Table 1. The assembled swabs were sterilised in a hot air oven at 160 °C for 1h and checked for sterility by surface swabbing on tryptic soy agar. Commercial cotton and viscose swabs were ethylene oxide-sterilised by the manufacturer.

2.4 Swab Validation

2.4.1 Absorbency Test

Swab absorbency was determined following a modified method of Zasada *et al*.[15]. The weight difference before and after immersion in 500 µL of molecular-grade water for 10 s was measured on a precision balance (Shimadzu BL-220H, Japan). The absorbed volume (v) was calculated using the following formula:

$$v = m/d$$

where m is the mass of absorbed water; and d, water density (1 g/cm³).

2.4.2 Microbiological Validation

Swabs were validated following the CLSI M40-A2 protocol[16]. Aerobic ATCC strains used included *Escherichia coli* ATCC 25922, *Haemophilus influenzae* ATCC 10211, *Klebsiella pneumoniae* subspecies *pneumoniae* ATCC 13882, *Pseudomonas aeruginosa* ATCC 27853, *Staphylococcus aureus* ATCC 25923, *Streptococcus pneumoniae* ATCC 6305 and *Streptococcus pyogenes* ATCC 19615. Semi-solid tryptic soy agar (TSA) and Amies medium with charcoal (HiMedia, India) were used as transport media. All experiments were conducted in triplicate. Colony-forming units (CFU) were enumerated, and log reductions computed.

2.4.3 Statistical Analysis

Differences in proportions between nettle versus cotton and nettle versus viscose swabs were analysed using MedCalc's Comparison of Proportions calculator[17]. The distribution of absorption, tip length and diameter, and bacterial reduction percentages was analysed by independent-sample Kruskal–Wallis tests using IBM SPSS Statistics (ver 20). A value of $P<0.05$ is considered statistically significant.

3 Results and Discussion

3.1 Fibre Characterisation

The morphological and chemical characteristics of nettle fibres are examined to assess the effects of retting and enzymatic bioscouring. SEM images (Fig. 3) show a clear distinction between untreated and treated fibres. The untreated bark [(Fig. 3(a)] exhibits a dense, compact structure, where cellulose fibres are embedded within a matrix of pectin and other non-cellulosic materials. After retting (Fig. 3(b)], partial removal of binding components occurs, leading to visible separation between fibre bundles. Enzymatic bioscouring further enhances this separation and produces smoother individual fibres [(Fig. 3(c)], confirming efficient degumming. The average fibre diameter ranges from 8 to 46 µm.

FTIR spectra (Fig. 4) confirm distinct structural changes between untreated and bioscoured nettle fibres. The bioscoured sample [(Fig. 4(a)] shows a broad absorption band at 3331 cm^{-1}, corresponding to O–H stretching vibrations due to hydrogen bonding in cellulose and hemicellulose. The absorption at 1027 cm^{-1} is attributed to C–O–C stretching of the pyranose ring in cellulose, confirming the integrity of the cellulosic backbone. In contrast, the untreated fibres [(Fig. 4(b)] exhibit a strong O–H stretching band at 3283 cm^{-1}, along with distinct C–H stretching peaks at 2916 cm^{-1} and 2848 cm^{-1}, characteristic of hydrocarbon structures associated with waxes and other impurities[11,18]. The marked reduction of these peaks in bioscoured fibres indicates effective removal of non-cellulosic substances such as waxes, lignin, and pectin during enzymatic processing.

The TGA curve of bioscoured nettle fibres (Fig. 5) reveals a multi-step thermal degradation pattern. An initial weight loss of approximately 5.97 % occurs below 110 °C due to moisture desorption. The fibres remain thermally stable up to 200 °C, beyond which gradual degradation of hemicellulose and pectin is observed between 200–300 °C[19]. The main degradation phase, corresponding to cellulose decomposition, occurs between 300–400 °C, with a major weight loss near 390 °C at a heating rate of 10 °C min^{-1}. The residual ash

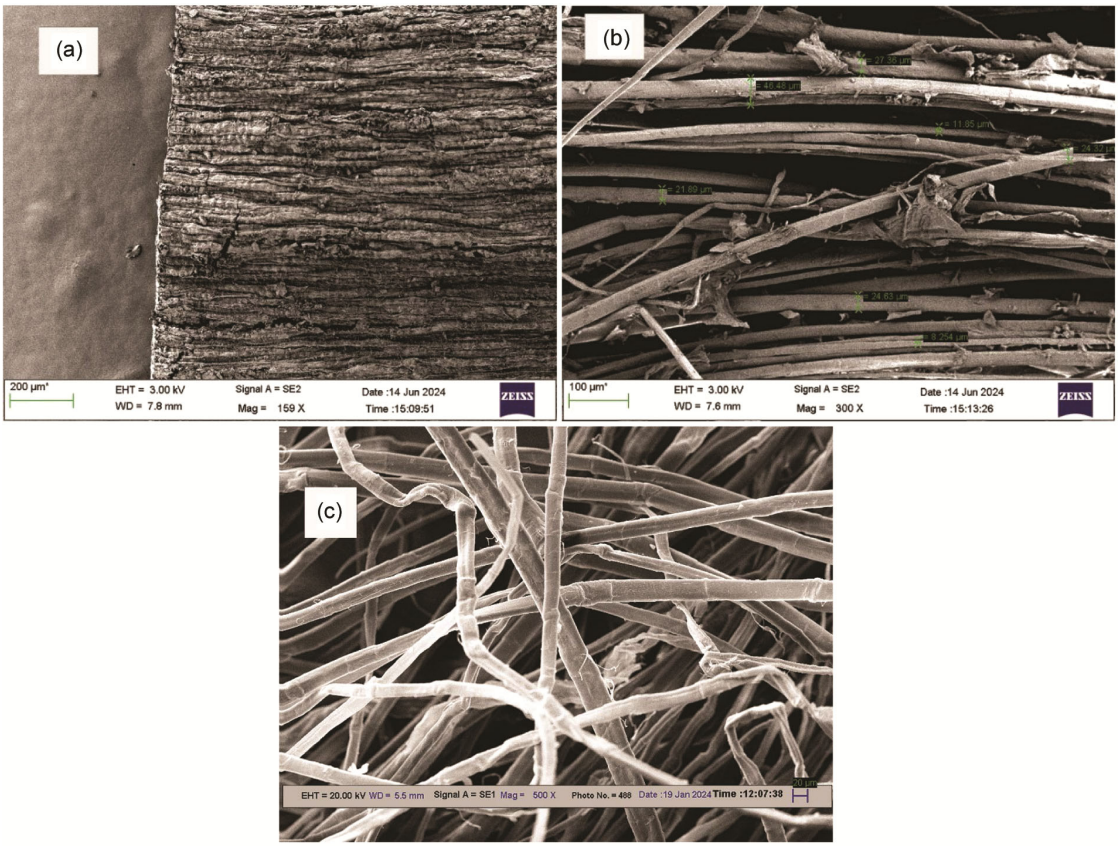

Fig. 3 — SEM images of nettle fibres (a) untreated bark, (b) bioretted fibres, and (c) bioscoured nettle fibres

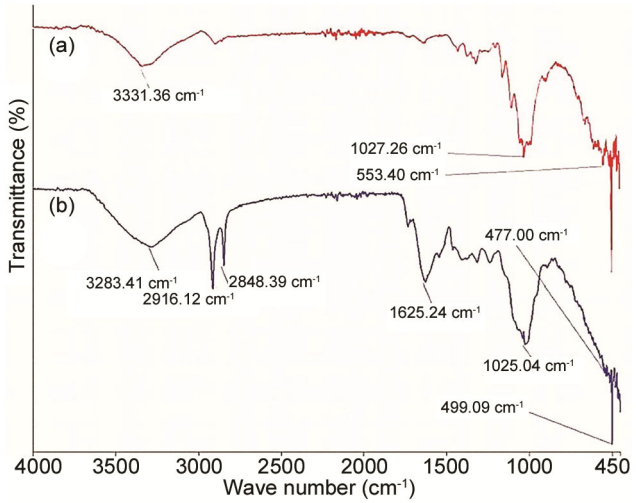

Fig. 4 – FTIR spectra of (a) bioscoured, and (b) untreated nettle fibres

content is about 13.61 %. These findings confirm that enzymatic bioscouring enhances fibre purity without compromising its thermal integrity.

3.2 Validation of Swabs

3.2.1 Absorption Capacity

The absorption capacity of nettle, cotton, and viscose fibre swabs is compared to evaluate their suitability for sample collection (Fig. 6). The average absorbed water volumes are 128 µL, 110 µL, and 160 µL for nettle, cotton, and viscose swabs, respectively. Statistical analysis reveals a significant difference in absorption capacity ($P = 0.17$) and tip length ($P = 0.008$), but no significant variation in tip diameter among the swab types.

The higher absorbency of viscose and nettle swabs is attributed to their longer tip lengths and looser wrapping, which facilitate better fluid uptake. Cotton swabs, with their finer and tightly wound fibres, show lower absorption. Although fibre-wrapped swabs demonstrate good absorbency, their recovery efficiency is generally lower than that of flocked swabs. Pre-wetting the swab with sterile liquid and using an appropriate transport medium are recommended to minimise sample loss, especially in low-volume or dry sampling conditions. Hence, an inoculating volume of 200 µL is adopted for subsequent bacterial validation tests to ensure adequate recovery.

3.2.2 Bacterial Validation Studies

The bacterial recovery performance of nettle fibre swabs (NFS) is evaluated against cotton (CFS) and

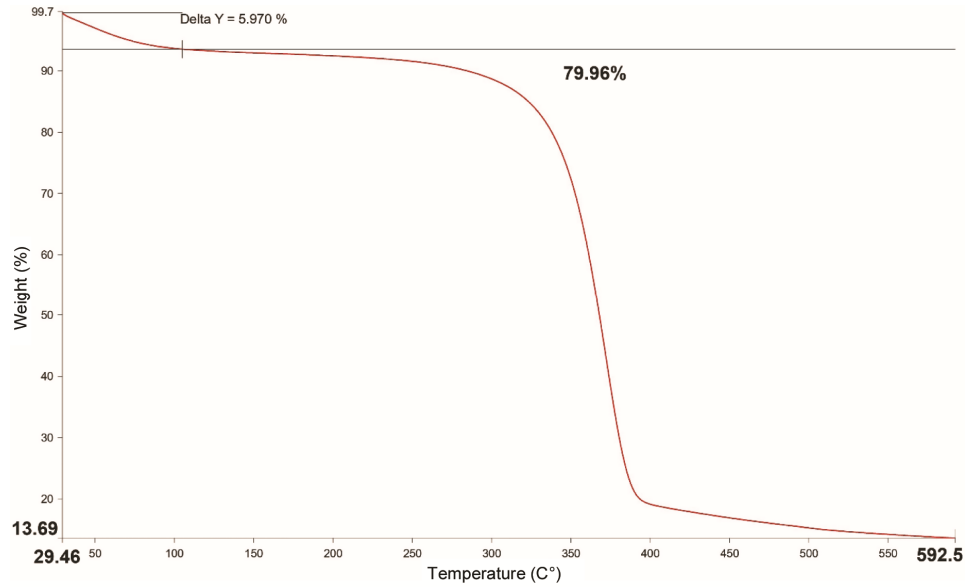

Fig. 5 — TGA curve of bioscoured nettle fibre

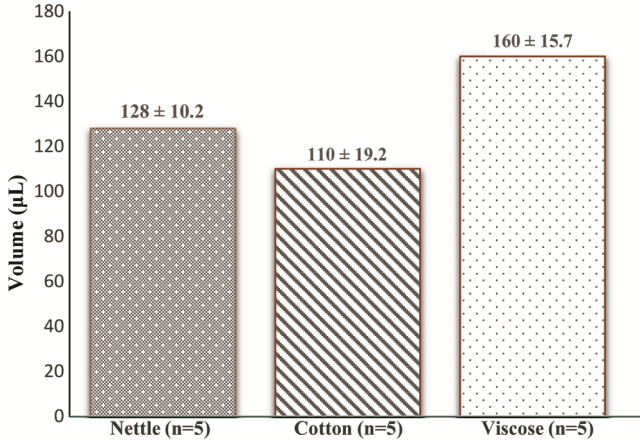

Fig. 6 – Volume of water absorbed by different swabs

viscose (VFS) swabs using roll plate (qualitative) and swab elution (quantitative) methods. A log decrease of more than 3 log units at both temperatures and a 1 log increase at refrigeration for *P. aeruginosa* was used as an acceptance criterion for the viability and overgrowth studies, respectively. Tables 2 and 3 show the log changes in bacterial counts over 48 h at room temperature (RT=22-28 °C) and 4–6 °C. The Kruskal–Wallis test indicates no significant difference in the distribution of percentage reduction across swab types, suggesting comparable overall performance.

For *E. coli*, NFS show superior recovery compared to CFS at 22-28 °C ($P < 0.0001$) and outperforms both CFS and VFS in elution tests at 4–6 °C for dilutions 10^4 ($P = 0.04$), 10^5 ($P = 0.0002$), and 10^6 ($P < 0.0001$) (data for lower dilutions not shown). At 22-28 °C, NFS perform better than VFS at dilutions of 10^3–10^6, confirming efficient bacterial release.

In *H. influenzae*, none of the swabs show satisfactory recovery at 22-28 °C for dilutions ≤ 10^4. NFS exhibit poor performance in both qualitative and quantitative methods. VFS perform relatively better, particularly at 22-28 °C ($P = 0.0008$ for 10^5; $P < 0.0001$ for 10^6). Storage beyond 24 h necessitates refrigeration at 4–6 °C to maintain bacterial viability.

NFS perform comparably to CFS and VFS for *K. pneumoniae* isolation, especially at 4-6 °C, with no significant difference in bacterial recovery across swab types and dilutions.

For *P. aeruginosa* isolation, VFS exhibit slightly better recovery at both temperatures by the roll plate method. However, in quantitative elution studies, NFS outperform both CFS and VFS, showing higher recovery at lower dilutions and across both temperatures.

Among Gram-positive cocci, NFS show comparable or superior recovery to CFS and VFS for *S. aureus* isolation at higher dilutions (≥ 10^5) by both methods. All swabs display complete reduction in growth at 10^2 dilutions by elution, with a noticeable decline in counts after 48 h.

For *S. pneumoniae* isolation, NFS perform similarly to VFS at 0 h inoculation and higher dilutions, but all swabs exhibit complete growth loss after 24 h at 4–6 °C. CFS inhibit pneumococcal growth even at 24 h. These results align with the

Table 2 — Qualitative analysis (Swab Roll-plate method) of bacterial recovery (10^6 CFU/mL) at different temperatures

Swab type	Temp.	0 h	24 h	48 h	Log-change	Compliance
			E. coli ATCC 25922			
Nettle	RT	>300	>300	254	-0.07	✓
	4-6 ℃		>300	219	-0.14	✓
Cotton	RT	>300	>300	200	-0.18	✓
	4-6 ℃		202	195	-0.19	✓
Viscose	RT	>300	>300	206	-0.16	✓
	4-6 ℃		223	200	-0.18	✓
			H. influenzae ATCC 10211			
Nettle	RT	>300	145	116	-0.41	✓
	4-6 ℃		>300	>300	0	✓
Cotton	RT	>300	125	106	-0.45	✓
	4-6 ℃		>300	277	-0.03	✓
Viscose	RT	>300	>300	>300	0	✓
	4-6 ℃		>300	>300	0	✓
			K. pneumoniae ATCC 13899			
Nettle	RT	>300	>300	233	-0.11	✓
	4-6 ℃		>300	267	-0.05	✓
Cotton	RT	>300	>300	227	-0.12	✓
	4-6 ℃		>300	249	-0.08	✓
Viscose	RT	>300	>300	200	-0.18	✓
	4-6 ℃		271	214	-0.15	✓
			P. aeruginosa ATCC 27853			
Nettle	RT	>300	>300	>300	0	✓
	4-6 ℃		>300	>300	0	✓
Cotton	RT	>300	>300	>300	0	✓
	4-6 ℃		>300	>300	0	✓
Viscose	RT	>300	>300	>300	0	✓
	4-6 ℃		>300	>300	0	✓
			S. aureus ATCC 25923			
Nettle	RT	>300	>300	236	-0.1	✓
	4-6 ℃		282	229	-0.12	✓
Cotton	RT	>300	>300	200	-0.18	✓
	4-6 ℃		77	65	-0.66	✓
Viscose	RT	>300	>300	164	-0.26	✓
	4-6 ℃		280	114	-0.42	✓
			S. pneumoniae ATCC 6305			
Nettle	RT	>300	140	97	-0.49	✓
	4-6 ℃		Nil	Nil	-4.48	×
Cotton	RT	>300	Nil	Nil	-4.48	×
	4-6 ℃		Nil	Nil	-4.48	×
Viscose	RT	>300	117	90	-0.52	✓
	4-6 ℃		Nil	Nil	-4.48	×
			S. pyogenes ATCC 19615			
Nettle	RT	>300	91	67	-0.65	✓
	4-6 ℃		34	28	-1.03	✓
Cotton	RT	>300	132	98	-0.49	✓
	4-6 ℃		37	24	-1.09	✓
Viscose	RT	250	121	105	-0.38	✓
	4-6 ℃		41	34	-0.95	✓

Table 3 — Quantitative analysis (swab elution method) of bacterial recovery (10^6 CFU/mL) at different temperatures

Swab type	Temp.	0-h	24-h	48-h	Log-change	Compliance
			E. coli ATCC 25922			
Nettle	RT	>300	277	210	-0.15	✓
	4-6 ℃		>300	202	-0.17	✓
Cotton	RT	>300	265	186	-0.21	✓
	4-6 ℃		190	117	-0.41	✓
Viscose	RT	>300	269	203	-0.17	✓
	4-6 ℃		223	219	-0.14	✓
			H. influenzae ATCC 10211			
Nettle	RT	234	21	2	-2.07	✓
	4-6 ℃		69	40	-0.77	✓
Cotton	RT	268	45	30	-0.95	✓
	4-6 ℃		114	86	-0.49	✓
Viscose	RT	243	120	101	-0.38	✓
	4-6 ℃		162	129	-0.28	✓
			K. pneumoniae ATCC 13899			
Nettle	RT	>300	271	214	-0.15	✓
	4-6 ℃		266	229	-0.12	✓
Cotton	RT	>300	268	210	-0.15	✓
	4-6 ℃		256	211	-0.15	✓
Viscose	RT	>300	234	220	-0.13	✓
	4-6 ℃		278	218	-0.14	✓
			P. aeruginosa ATCC 27853			
Nettle	RT	>300	>300	>300	0	✓
	4-6 ℃		>300	261	-0.06	✓
Cotton	RT	>300	276	230	-0.12	✓
	4-6 ℃		288	270	-0.05	✓
Viscose	RT	>300	278	251	-0.08	✓
	4-6 ℃		>300	276	-0.04	✓
			S. aureus ATCC 25923			
Nettle	RT	>300	243	192	-0.19	✓
	4-6 ℃		218	201	-0.17	✓
Cotton	RT	265	194	189	-0.15	✓
	4-6 ℃		136	120	-0.34	✓
Viscose	RT	>300	255	130	-0.36	✓
	4-6 ℃		170	161	-0.27	✓
			S. pneumoniae ATCC 6305			
Nettle	RT	58	35	28	-0.32	✓
	4-6 ℃		Nil	Nil	-5.06	✗
Cotton	RT	52	Nil	Nil	-5.02	✗
	4-6 ℃		Nil	Nil	-5.02	✗
Viscose	RT	3	Nil	Nil	-3.78	✗
	4-6 ℃		Nil	Nil	-3.78	✗
			S. pyogenes ATCC 19615			
Nettle	RT	111	56	48	-0.36	✓
	4-6 ℃		42	30	-0.57	✓
Cotton	RT	21	17	14	-0.18	✓
	4-6 ℃		19	18	-0.07	✓
Viscose	RT	188	89	75	-0.39	✓
	4-6 ℃		58	40	-0.67	✓

WHO Pneumococcal Carriage Working Group's recommendation[20] that natural fibre swabs be cultured within 8 h of collection.

NFS performance is equal to CFS and VFS for isolating *S. pyogenes*. All swabs show poor recovery beyond 24 h, with a sharp decline in growth at 10^6 dilutions and 100 % reduction below 10^5. Therefore, all the swabs were appropriate for immediate inoculation only. The poor recovery of *S. pyogenes* can be attributed to factors such as the poor release offered by the swab design, rather than just the toxic effects of cotton fibres, which were not the only type of fibre used. The other impeding factors could be the Amies transport media, increased moisture or the low temperature that was detrimental to the survival of *S. pyogenes* on a swab[21].

Across all tests, the three swabs perform better for Gram-negative bacilli than gram-positive cocci, with the weakest results for *S. pneumoniae*. Minimal differences are observed between 0-h and 24 h counts for *E. coli*, *K. pneumoniae*, and *P. aeruginosa*, while refrigerated swabs show reduced growth for *Streptococcus* species. Therefore, if transport is delayed beyond 24 h, none of the swabs are suitable for *Streptococcus* isolation, whereas refrigeration improves the recovery of gram-negative bacteria and *H. influenzae*.

Structurally, NFS and VFS possess loosely wound tips that enhance absorption and release, unlike the compact, tightly wound CFS tips, which limit uptake and fluid release. Tip fraying is observed in both NFS and CFS, whereas fibre shedding is more frequent in CFS. Despite these differences, NFS demonstrate adequate absorbency, bacterial recovery, and handling characteristics, establishing them as a viable, sustainable alternative to conventional cotton swabs.

4 Conclusion

This study demonstrates that nettle fibre swabs (NFS) exhibit comparable or slightly superior performance to conventional cotton (CFS) and viscose fibre swabs (VFS) in terms of absorption and bacterial recovery. SEM, FTIR, and TGA analyses confirm that bioscouring effectively removes non-cellulosic impurities, improving fibre separation, smoothness, and thermal stability. The absorption capacity of NFS is higher than CFS and close to VFS, making it suitable for sample collection under varied conditions.

In bacterial validation, NFS performs efficiently for *E. coli*, *K. pneumoniae*, and *S. aureus* isolation, particularly at 4–6 °C, while maintaining comparable recovery to other swabs. However, all swabs show poor recovery for *Streptococcus pneumoniae* and *S. pyogenes* beyond 24 h, highlighting the importance of timely processing. Overall, nettle fibre emerges as a promising sustainable alternative for medical and microbiological swab applications, combining adequate absorbency, microbial compatibility, and biodegradability.

Acknowledgement

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