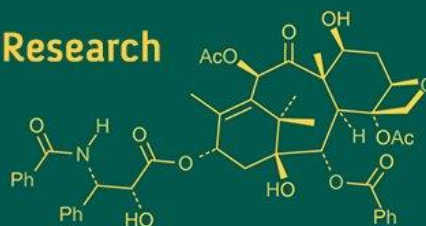
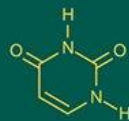


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Development and characterization of citronella oil- fragranced cotton sewing thread for functional textile applications

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Abstract

Sewing thread is present in almost every finished textile product, yet it remains an underexplored substrate for functional finishing. This paper reports the development of a citronella oil-fragranced cotton sewing thread, produced by coating unfinished cotton thread with citronella oil-treated paraffin wax during a conventional yarn-winding step, and examines the effect of this treatment on the thread's physical properties and surface morphology. Citronella oil was blended into molten paraffin wax at a fixed loading and applied to the thread; an untreated (without-wax) thread and a plain-wax-coated thread served as controls. Count, twist, tenacity, elongation, and breaking strength were measured before treatment and after 1, 5, 10, 15, and 20 washes, and the thread surface was characterised by field-emission scanning electron microscopy (FE-SEM) and energy-dispersive X-ray spectroscopy (EDX). Citronella oil-treated thread showed the highest tenacity (69.32-69.38 g/tex), elongation (13.92%, mean 6.1 cm) and breaking strength (1320 g) of the three groups, exceeding both the without-wax and plain-wax controls, and these gains in elongation ($F = 4.02$, $p < 0.05$) and tenacity ($F = 40.48$, $p < 0.05$) were statistically significant. Mechanical properties declined only modestly through twenty washes. FE-SEM showed a visibly smoother thread surface after treatment, and EDX confirmed carbon, oxygen, nitrogen, and calcium on the coated surface, with a comparatively higher calcium peak on citronella-treated thread than on untreated thread. These findings indicate that a citronella oil-paraffin wax coating is a simple, low-cost way to functionalise cotton sewing thread that, in this study, modestly improved rather than compromised its mechanical performance.

Keywords: Citronella oil, cotton sewing thread, paraffin wax coating, tenacity, elongation, FE-SEM, EDX

1. Introduction

Fragrance finishing of textiles has expanded from home textiles and apparel into technical and functional niches, using perfume-retention agents such as cyclodextrins, elastomer/synthetic-resin emulsions, thermoplastic microcapsules, and coating formulations to extend the duration of scent release on a substrate (Bezerra *et al.*, 2020; Astray *et al.*, 2009) [3, 2]. Commercial microencapsulation applications for textiles began emerging in the early 1990s and have since expanded, particularly in Western Europe, Japan, and North America, as manufacturers pursue new functional and value-added textile properties (Nelson, 1991) [5].

Citronella oil, an essential oil derived from *Cymbopogon* (lemongrass) species, is a natural, non-toxic material long used in perfumery and cosmetics and recognised as an effective insect repellent. Because it is a volatile, monoterpene-rich oil, however, a citronella finish applied directly to a textile surface tends to lose fragrance and repellent activity over time and washing unless it is chemically bound to, or encapsulated within, the substrate (Specos *et al.*, 2010) [7]. Sewing thread offers a distributed, largely unexplored route for building fragrance into a finished garment (Tarrant, 1994) [8], and coating thread with a fragrance-loaded paraffin wax during the routine thread-waxing step is, in principle, a simpler and lower-cost alternative to microencapsulation. Because any such coating could in principle also alter the thread's mechanical behaviour, this paper focuses specifically on how a citronella oil-paraffin wax coating affects the physical properties (count, twist, tenacity, elongation, strength) and surface morphology of cotton sewing thread, independent of the sensory/consumer dimension of the

fragrance, which is reported separately.

2. Literature Review

Citronella oil applied to cotton fabric by conventional padding has been reported to give high initial mosquito repellency that diminishes within about three weeks because the oil is not chemically bound to the fibre surface (Specos *et al.*, 2010) ^[7]. Encapsulating citronella oil by complex coacervation before application has been shown to improve durability markedly, with treated cotton retaining repellency above 90% for around three weeks (Specos *et al.*, 2010) ^[7], and microencapsulated citronella oil applied at higher loadings to polyester-cotton blends has been reported to retain 80% mosquito repellency after 30 industrial-type washes while preserving comfort properties such as air permeability and water absorbency (Reis *et al.*, 2022) ^[6]. More broadly, microencapsulation of essential oils in biodegradable polymeric carriers is an established route for cosmetic and textile applications where a controlled, extended release of the active oil is required (Martins *et al.*, 2014; Verma *et al.*, 2023) ^[4, 9].

Comparatively little of this literature reports the effect of essential-oil or wax-based fragrance finishes on the mechanical performance of the treated substrate itself, as opposed to fragrance/repellent durability. Because paraffin wax is already used industrially to reduce friction and improve the sewability of cotton thread, a wax-based citronella carrier is of particular interest as a route that might combine fragrance delivery with the wax's known lubricating and reinforcing action on the thread.

3. Materials and Methods

3.1 Materials

Unfinished cotton sewing thread was procured from a local thread supplier in Kanpur, Uttar Pradesh. Paraffin wax and citronella essential oil were purchased from the local market in Kanpur; citronella oil was selected for the study as a natural, non-toxic source of fragrance with reported insect-repellent and medicinal properties.

3.2 Preparation of Citronella Oil-Treated, Wax-Coated Sewing Thread

Paraffin wax was melted at 100°C and 5 ml of citronella oil was mixed into the molten wax. The softened, fragranced wax was moulded into a rounded shape using a mould and left to cure for 15–20 minutes until solid. The untreated cotton sewing thread was then passed through the cured, citronella oil-treated wax on a yarn winder, coating the thread surface with fragranced wax as it passed through. A plain-wax control (no added oil) and an untreated, without-wax control were prepared/retained in the same manner for comparison. Paraffin wax was selected as the carrier because it is non-toxic and, independent of any fragrance, is understood to improve the lustre, elongation, tenacity, and smoothness of coated thread.

3.3 Instruments Used

A wrap-reel (skein winder) was used to prepare standard hanks; a Twist-Per-Inch (TPI) tester to measure yarn twist; a quadrant balance/Knowles balance to determine yarn count;

a pendulum-lever yarn and thread tensile-strength tester to measure tenacity and elongation; a yarn-winding machine to apply the wax coating; and a field-emission scanning electron microscope (FE-SEM), with an attached energy-dispersive X-ray (EDX) detector, to characterise thread surface morphology and elemental composition.

3.4 Testing of Physical Properties

Yarn count was determined with a Knowles balance following calibration to zero and preparation of a 120-yard lea on a wrap wheel; the count was read from the beam once balanced.

Yarn twist was measured with a single-yarn twist tester: a 10-inch length of yarn was clamped under light tension, fully untwisted, and then re-twisted to return the pointer to zero, with the number of turns recorded on a revolution counter. Turns per inch (TPI) were calculated as:

$$\text{TPI} = \text{Final reading} / (\text{Effective length} \times 2)$$

Tenacity and elongation were measured with the pendulum-lever strength tester over ten replicate tests per sample, clamping the sample between upper and lower jaws and recording the breaking load and elongation-scale reading (Angappan & Gopalakrishnan, 1993) ^[1]:

$$\text{Tenacity (g/tex)} = (\text{Mean breaking load in kg} / \text{Tex}) \times 100$$

$$\text{Elongation (\%)} = (\text{Elongation-scale reading} / \text{Gauge length}) \times 100$$

Thread diameter was additionally noted as a factor governing sewability, since it must be compatible with the needle-eye size to avoid seam puckering or thread breakage.

3.5 Thread Morphology

FE-SEM (Zeiss, Switzerland) images of treated and untreated thread were obtained at 5–10 kV operating voltage. Samples were mounted on aluminium stubs with carbon tape, sputter-coated with 5 nm gold–palladium under vacuum (8–10 mbar), and imaged under argon to minimise surface reaction prior to scanning. EDX was performed alongside SEM imaging to determine surface elemental composition.

3.6 Statistical Analysis

Group means, standard deviation, variance, and median were computed for elongation and tenacity, and Pearson correlation coefficients were calculated between treatment groups. Analysis of variance (ANOVA), F-tests, standard error of the difference, and critical difference (CD) at the 5% level were used to test the significance of differences between treatment means.

4. Results and Discussion

4.1 Physical Properties of Citronella-Treated Sewing Thread

Table 1 summarises the elongation, strength, tenacity, twist, and count of the without-wax control, the plain-wax control, and the citronella-treated thread, together with the citronella-treated thread's values after 1, 5, 10, 15, and 20 washes.

Table 1: Physical properties of untreated, plain-wax, and citronella oil-treated sewing thread with subsequent washes

Sample	Elongation (cm)	Elongation (%)	Strength (g)	Tenacity (g/tex)	Twist/inch	Count (Tex/Ne)
Without wax	5.0	11.41	1280	68.30	19	18.74
Plain wax	5.1	11.64	1310	68.80	19	19.04
Citronella (0 wash)	6.1	13.92	1320	69.32	20	19.04
After 1 wash	6.1	13.92	1320	69.32	20	19.04
After 5 washes	6.1	13.92	1310	68.87	20	19.04
After 10 washes	5.7	13.01	1300	68.49	19	18.98
After 15 washes	5.5	12.55	1300	68.49	19	18.98
After 20 washes	5.4	12.32	1300	68.75	19	19.04

The citronella-treated thread showed the highest tenacity (69.32 g/tex), elongation (13.92%), and breaking strength (1320 g) among the three initial samples, exceeding both the without-wax and plain-wax controls. Values remained close to the initial figures through five washes and declined only modestly by the twentieth wash, suggesting that the wax coating — not only the fragrance component — contributes measurable mechanical reinforcement that persists reasonably well under repeated laundering.

Table 2: Elongation of without-wax, plain-wax, and citronella-treated sewing thread

Group	Mean	S.D.	Variance	Median
Without wax	5.0	0.50	0.25	5
Plain wax	5.1	0.65	0.43	5
Citronella	6.1	0.42	0.18	6

Analysis of variance across groups was significant ($F = 4.02$, $p < 0.05$; S.E. of difference = 0.38; C.D. (0.05) = 0.80), confirming that citronella treatment produced a genuine increase in elongation.

Table 3: Tenacity of without-wax, plain-wax, and citronella-treated sewing thread

Group	Mean	S.D.	Median	Variance
Without wax	68.12	0.14	68	0.02
Plain wax	68.50	1.33	68	0.11
Citronella	69.38	0.14	69	0.02

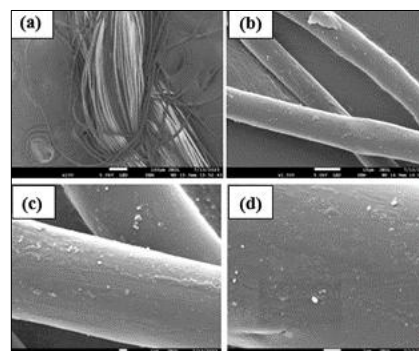
Tenacity differences were highly significant across groups ($F = 40.48$, $p < 0.05$; S.E. of difference = 0.13; C.D. (0.05) = 0.28), with citronella-treated thread again outperforming both controls.

Correlation analysis showed the elongation of citronella-treated thread was weakly, negatively correlated with the without-wax control ($r = -0.076$) and negligibly correlated with plain wax ($r = 0.001$), indicating that the wax-and-fragrance treatment altered elongation behaviour relative to the untreated state rather than simply scaling it. A similar pattern held for tenacity, where citronella-treated thread was negatively correlated with the without-wax control ($r = -0.264$) and moderately positively correlated with the plain-wax control ($r = 0.500$), suggesting the paraffin-wax carrier itself accounts for part of the tenacity gain, with citronella oil contributing an additional increment.

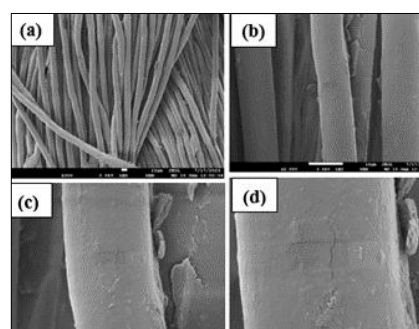
4.2 Surface Morphology and Elemental Composition

FE-SEM imaging showed that citronella oil-treated sewing thread had a visibly smoother surface structure than both the plain-wax-coated and the without-wax thread, consistent with the wax-and-oil coating filling surface irregularities on the cotton fibres. EDX analysis detected carbon, nitrogen, oxygen, and calcium on the thread surface, with carbon and oxygen peaks predominant across both treated and untreated samples; citronella-treated thread additionally showed a comparatively higher calcium peak than untreated thread, which may reflect trace mineral content carried in with the oil

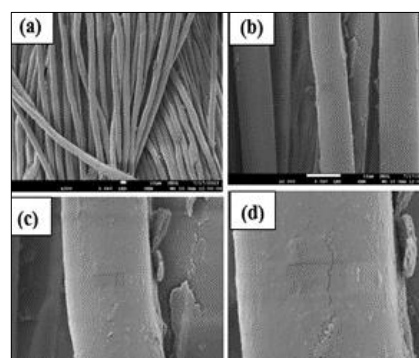
or wax coating.



FE-SEM image of Morphology structure of treated with citronella oil in sewing thread at different magnifications (a) x100, (b) x1500, (c) x4,500, (d) x10,000



FE-SEM image of Morphology structure of treated with citronella oil after 5 wash in sewing thread at different magnifications (a) x300, (b) x2000, (c) x4,500, (d) x10,000



FE-SEM image of Morphology structure of treated with citronella oil after 20 wash in sewing thread at different magnifications (a) x500, (b) x3000, (c) x6,500, (d) x15,000

5. Conclusion

Coating cotton sewing thread with citronella oil-treated paraffin wax during a conventional yarn-winding step measurably improved the thread's tenacity, elongation, and breaking strength relative to untreated and plain-wax-coated

controls, with the improvements in elongation and tenacity statistically significant at the 5% level. The mechanical gains persisted with only modest decline through twenty washes, and FE-SEM/EDX confirmed a smoother, wax-and-oil-coated surface bearing the expected carbon-, oxygen-, nitrogen-, and calcium-containing surface chemistry. These results indicate that a citronella oil-paraffin wax coating is a viable, low-cost route to functionalising cotton sewing thread without compromising — and in this case modestly enhancing — its mechanical performance. The fragrance intensity, durability under laundering, and consumer acceptance of this same treated thread are examined in a companion paper.

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