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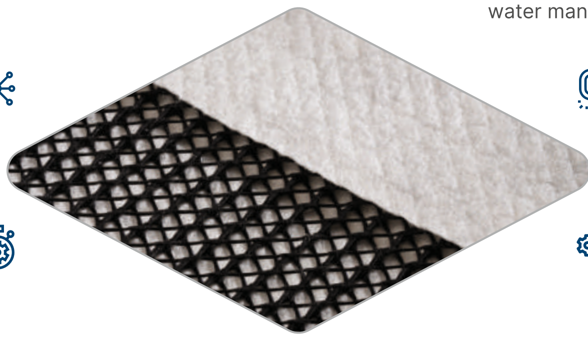

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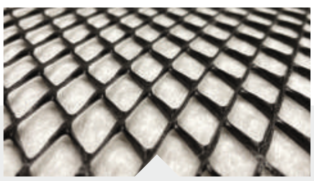

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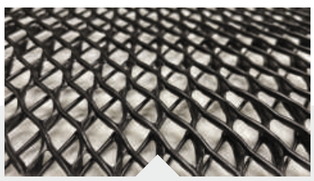

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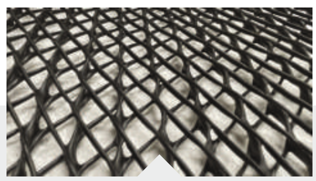

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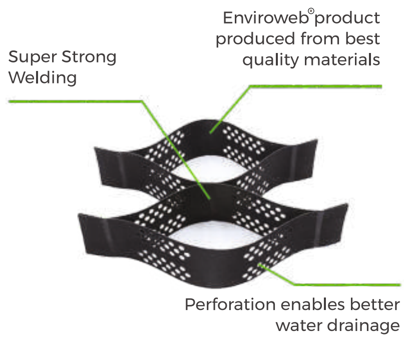

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EDITOR'S DESK

Dear Readers,

Greetings!!

Research with persistent and focused efforts lead to a positive result. Fostering research and providing a platform to publish quality research papers and related articles has been a continuous effort of BTRA Scan. We are working hard to help the journal in climbing up the ranking ladder. In continuation to this effort, I am delighted to present to our readers the 3rd issue of 54th Edition of BTRA SCAN.

This issue has 3 papers from the different domains such as development of sustainable aroma and mosquito repellent finish, a review on cutting-edge utilization of uhmwpe polymer in industrial and medical applications and biosynthesized silver nanoparticles asantimicrobial finish over cotton fabric. Now we are open for authors from outside so researchers can send their original articles, case studies, research reviews or empirical contributions for publication in our journal.

I thank my entire publishing team for all their support. Together we would work towards making the journal a truly influential publication. Comments and suggestions are always welcome.

Our sincere thanks to all the reader and contributors for their support and interest.

T V Sreekumar, PhD
Director, BTRA

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Development of sustainable aroma and mosquito repellent finish for textiles

M. P. Sathianarayanan, Karishma Hemani & Shraddha Nitturkar
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Abstract

Functional finishing of textiles has been in great demand since the last two decades in domestic and industrial applications. Mosquito repellent textiles are one of the most demanded functional finished textiles in the current market. The investigation of this research is to study the combined effect of fragrance and mosquito repellant property on cotton fabric by using Lavender and Citronella essential oil by means of nano encapsulation. Nano encapsulated essential oil prepared via sol gel process and is applied on cotton fabric through nip-pad-dry method. The treated fabric is found to have good mosquito repellant property with reasonable wash durability up to five domestic washes. The aroma release of transformed tissue and washed fabric was estimated by chromatography/mass spectrometry of head space (HS-GC/MS) by measuring the concentration of the main components in tissue treated with essential oils. The results reveal that in each wash cycle, the essential oil is released from the treated fabric as the concentration of chemical compounds decreases gradually. A panel assessment and a field trial of mosquito repellant property have been done to validate the HS –GC/ MS study.

Keywords

Citronella, HS GC/ MS, Lavender, Mosquito repellant, Nano encapsulation, Sol gel.

Citation

M.P Sathianarayanan, Karishma Hemani & Shraddha Nitturkar, “Development of sustainable aroma and mosquito repellent finish for textiles”, *BTRA Scan* - Vol. LIV No.3 , July, 2025, Page no. 5 to 12, DOI: 10.70225/783640mzvikz

1.0 Introduction:

Aroma-functional textiles such as bed covers, tablecloths, and curtains have witnessed increasing market demand due to their enhanced aesthetic and therapeutic appeal [1]. Among functional textile categories, mosquito-repellent fabrics hold particular significance due to growing public health concerns and the demand for personal protection [2,3]. However, the direct application of essential oils to textiles presents challenges related to their high volatility and limited chemical stability. Aroma delivery in textiles relies on the volatility and sufficient concentration of fragrance compounds, enabling diffusion to the olfactory epithelium and subsequent perception by the olfactory centre in the brain [4–7]. To address the volatility and short-term efficacy of essential oils, nano-encapsulation techniques have emerged as an effective strategy to modulate the release rate of volatile compounds, thereby extending their functional lifespan [8–10]. Nano-encapsulation of aroma compounds using inorganic or hybrid matrices has gained considerable interest for textile finishing. Various fabrication methods for aromatic nano-capsules have been reported in literature [11,12], with the sol-gel technique standing out due to its simplicity, tunability, and suitability for fabric applications.

In this study, a sol-gel encapsulation approach was employed to entrap citronella oil (a known mosquito repellent) and lavender oil (used in aromatherapy for alleviating insomnia), aiming to develop multifunctional cotton textiles with both mosquito-repellent and aromatic properties. The synthesized nano-capsules containing the essential oils were applied onto cotton fabric using the pad–dry method to ensure even distribution and adhesion. To evaluate the wash durability of the treatment, the release behaviour of citronella oil post-laundering was quantified indirectly through analysis of its key volatile constituents using headspace gas chromatography–mass spectrometry (HS-GC-MS). Additionally, the mosquito-repellent efficacy was assessed through a combination of field exposure tests and subjective evaluations obtained from a user panel.

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2.0 Material and analytical methods

2.1 Materials

- Lavender oil and Citronella oil purchased from Nishant aromas Pvt Ltd Uttarakhand.
- Fresh lemongrass procured from Mumbai market.
- Tween 80 , Citric acid and Ammonium hydroxide were purchased from Merck India Ltd.
- Ethanol purchased from Gogia and company, Mumbai.
- Tetraethyl orthosilicate (TEOS), Hexadecyl-trimethoxysilane (HDTMS), Methyltriethoxysilane (MTES) were purchased from Sigma Aldrich.
- 100% cotton fabric purchased from Kiran threads, Mumbai.

2.2 Equipments

The following equipments were used in this project work.

Shimadzu QP2020 NX GC MS, Ultrasonic bath, Magnetic stirrer and Oven.

2.3 Methods

2.3.1 Analysis of essential oil

Purchased Lavender oil and Citronella oil was analyzed to assess the purity and fragrance components. Chemical components and purity of the essential oil was analyzed by Gas Chromatography Mass Spectrometer. Major Components in Lavender oil were found to be Linalool, Linalyl acetate and lavendulyl acetate. Major components in Citronella oil were found to be Citronellal, Geraniol, Citronellol , Limonene and Citral.

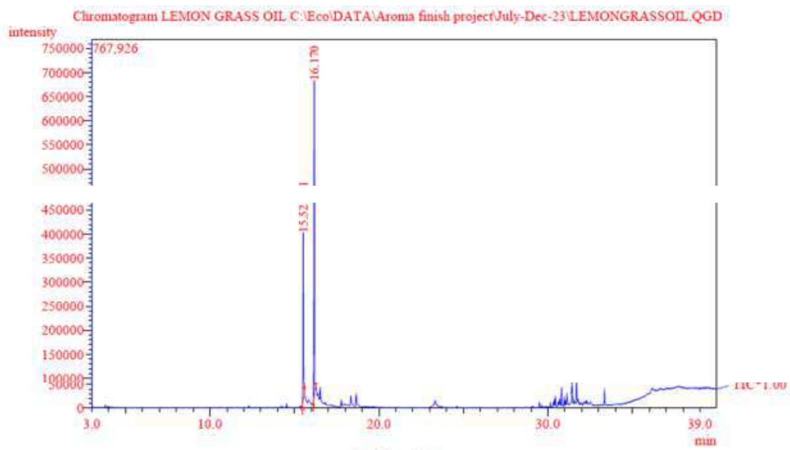
2.3.2 Distillation of lemongrass

Fresh lemon grass procured from Mumbai local market (Fig-1) was also steam distilled and the essential oil was recovered by using liquid –liquid extraction with hexane. Steam distillation set up is shown in Fig-2. 2.0 % (yield) pure oil was recovered from fresh lemon grass. GC MS Chromatogram of distilled lemongrass oil and commercial

Figure 1. Lemon grass collected from local market

Figure 2. Photograph of steam distillation set up of lemon grass oil

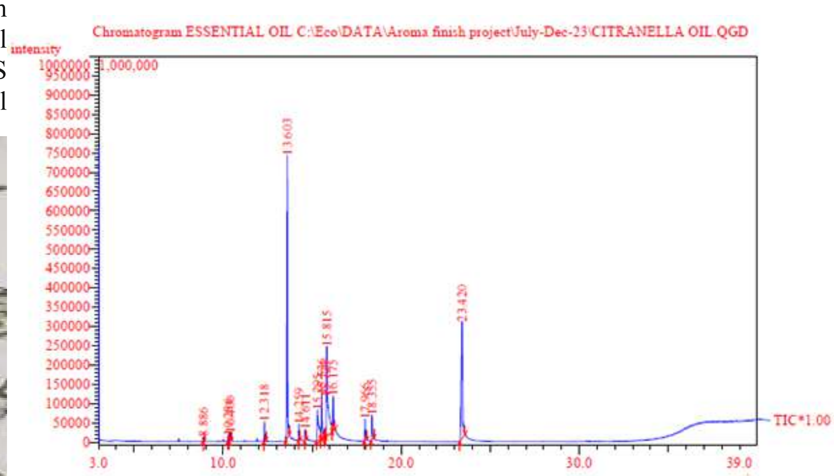
citronella oil is given in Fig 3 & 4 respectively. Purity of the distilled lemongrass oil was found to be better than the commercially available one.



Peak Report TIC

Peak#	R.Time	Area	Area%	Height	Base m/z	Name
1	15.521	934239	33.98	382920	41.05	Beta Citral
2	16.170	1815089	66.02	657228	69.10	Alpha Citral
		2749328	100.00	1040148		

Figure 3. GC MS Chromatogram of lemongrass oil



Peak Report TIC

Peak#	R.Time	Area	Area%	Height	Base m/z	Name
1	8.886	24855	0.36	11521	93.10	Beta Pinene
2	10.286	37823	0.54	15482	119.15	Para Cymene
3	10.400	52262	0.75	21584	68.05	D- Limonene
4	12.318	134803	1.94	52658	71.05	Linalool
5	13.603	2001174	28.74	734436	41.05	Citronellal
6	14.259	102904	1.48	41646	71.05	4-Terpinol
7	14.611	77198	1.11	29010	59.05	Alpha Terpinol
8	15.295	505279	7.26	80222	41.05	Citronellal
9	15.536	394859	5.67	115152	41.05	Beta Citral
10	15.729	70695	1.02	25991	93.10	Linalyl acetate
11	15.815	1325322	19.04	233911	69.10	Geraniol
12	16.175	295048	4.24	91465	41.05	Alpha Citral
13	17.966	150903	2.17	56094	69.10	Neryl acetate
14	18.355	205452	2.95	64873	69.10	Geranyl acetate
15	23.420	1583322	22.74	303552	149.10	Di ethyl phthalate
		6961899	100.00	1877597		

Figure 4. GC MS chromatogram of citronella oil

2.3.3 Application and evaluation of wash durability of Citronella oil & Lavender oil on cotton fabric.

2.3.3.1 Preparation of sol gel solution

A solution comprising ethanol (200 ml), water (8 ml), and ammonia (10 ml) was added to a 500 ml reactor flask. The experimental setup comprised a reflux condenser, a magnetic stirrer, and a dropping funnel, all assembled on a thermostat-regulated heating mantle. The reaction temperature was consistently maintained at 85 ± 1 °C, while the stirring speed was fixed at 850 rpm to ensure homogeneous mixing. Reagents were introduced dropwise via the dropping funnel to facilitate controlled addition and maintain thermal stability throughout the reaction process. and a dropping funnel. A mixture of 21 ml tetraethylorthosilicate (TEOS) and 13 ml ethanol was added drop wise into the reactor while maintaining the same temperature and stirring speed. The reaction continued at 85 °C for 2 hours. Subsequently, the temperature was increased to 100 °C, and a second mixture comprising 9 ml methyltriethoxysilane (MTES) and 25 ml ethanol was introduced into the flask. The reaction was allowed to continue for 24 hours under the same stirring speed (850 rpm) and temperature (100 °C). At the end of the process, SiO_2 nano-particles (nano-SiO_2 sol) were obtained. In the sol-gel process, the solution (sol or gel) enables the transition of metal-organic precursors into a solid, often through hydrolysis and condensation reactions, forming an inorganic polymer network. The poly condensation reaction

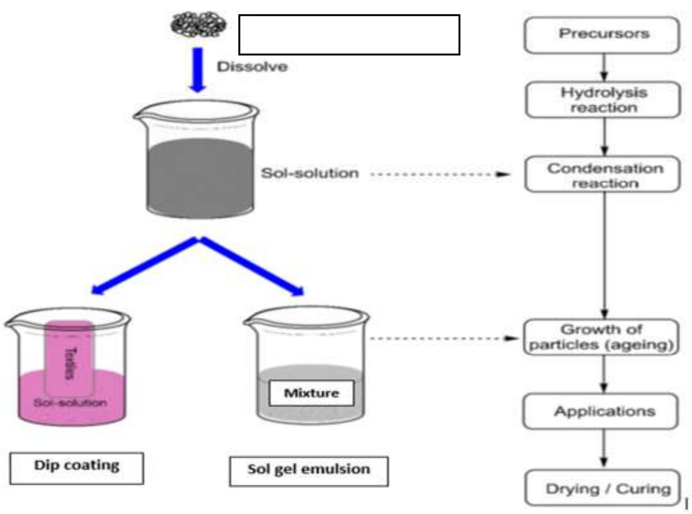


Figure 5. various stages of sol gel synthesis

transforms Si-OR to Si OH – comprising species into siloxane compounds which is the basic chemical principle of sol gel treatment of silica- based material. fig- 5 represents the various steps of sol gel formation.

2.3.3.2 Encapsulation of Essential Oils in Mesoporous Silica

10 % Essential oils (citronella and lavender) were encapsulated into the above prepared mesoporous silica, along with 1 ml surfactant (Tween 80), 20 ml citric acid (1% solution), and 10 ml hexadecyltrimethoxysilane (HDTMS). The mixture was stirred at 850 rpm for 3 hours at room temperature. The encapsulated oil-loaded mesoporous silica was then collected for further characterization and application. Fig. 6 illustrates the physicochemical reaction of nano encapsulated oil in sol gel.

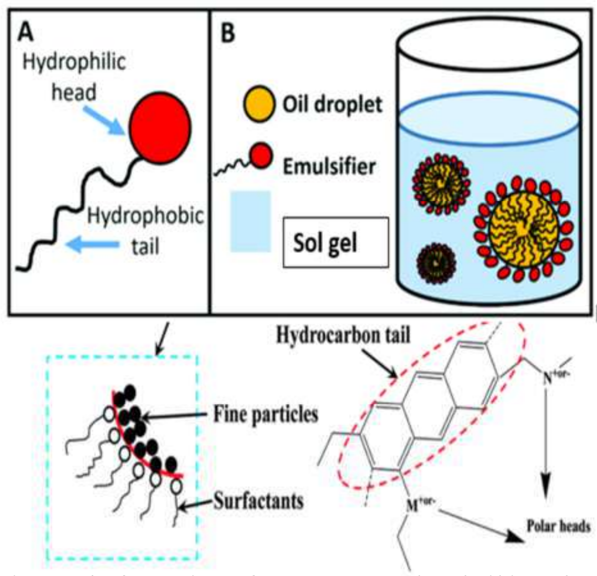


Figure 6. formation of nano encapsulated oil in sol gel

2.3.3.3 Aroma Nano-Capsule Wall Material synthesis

The sol-gel process is widely used as a physicochemical method to fabricate nano capsules using metal oxides. It allows precise control over morphology and ensures uniform encapsulation of active ingredients under mild conditions. The general sol-gel encapsulation process consists of four main steps:

1. Formation of an aqueous droplet by mixing a metal oxide precursor, solvent, and surfactants (sol phase),
2. Gelation via precursor polymerization to form an oxide matrix,
3. Addition of the active ingredient (essential oil),
4. Encapsulation of the active agent within the forming matrix.

The chemical reactions of sol-gel and formation of oil nano capsules is given in Fig.7 .

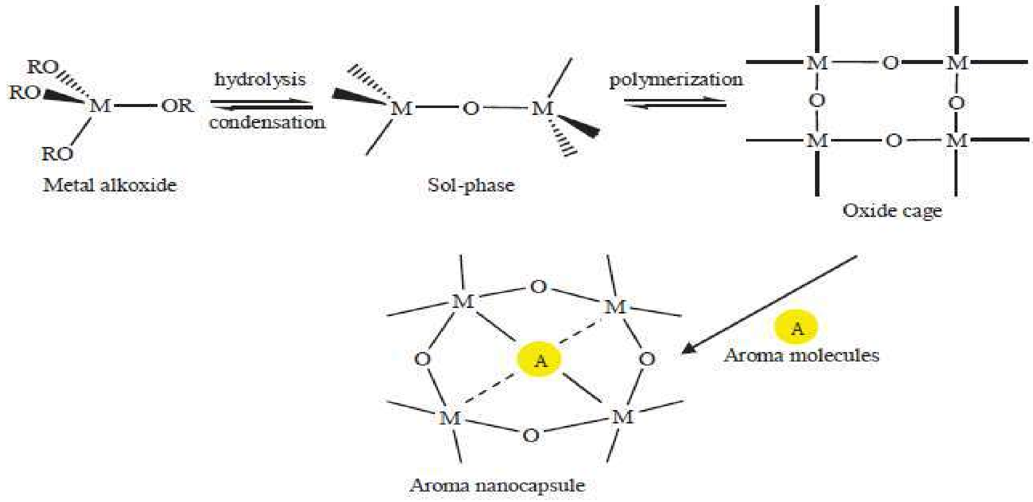


Figure 7. Chemical reactions of oil sol-gel, and formation of oil nano capsules

2.3.3.4 Application of nano capsules on to Cotton Fabric

The applications on cotton fabric take place in two stages. In the first stage, synthesized nano-SiO_2 sol applied on to cotton fabric by nip–pad–dry-cure method. The fabric was dried at 80oC for 5 min and cured at 130 °C for 5 minutes. In the second stage of application, fabric was treated with encapsulated aroma sol gel by spraying on both sides of fabric by using a spray gun. A final curing step was performed at 110 °C for 2 minutes.

The chemical modification of the fabric occurred in two main stages. In the first stage, when a sol- gel is applied on cotton fabric, the nano – SiO2 particles are deposited on the surface of cotton fabric. A condensation reaction occurs between the hydroxyl (-OH) groups on the cotton fabric surface and the silanol groups of the silica precursor, resulting in covalent bonding of SiO_2 to the cellulose matrix. The deposition of silica nanoparticles on the fabric surface effectively reduces surface energy, thereby enhancing the hydrophobicity of the textile material. The presence of methyl ($-CH_3$) functional groups further contributes to the hydrophobic nature of the SiO_2 particles. The synergistic effect of the Nano-scale roughness imparted by SiO_2 and the intrinsic micro-scale texture of the cotton substrate produces a hierarchical or binary roughness. This dual-scale surface morphology significantly improves the water-repellent properties of the treated fabric by altering its wetting behaviour. In the subsequent step, the sol–gel treated fabric undergoes a surface modification with hexadecyl-trimethoxysilane (HDTMS). In aqueous ethanol, HDTMS hydrolyses to form alkyl silanols, which can further condense with available hydroxyl or silanol groups on the SiO_2-modified surface, leading to the formation of a low-energy hydrophobic layer. These react with the surface hydroxyl groups to form a self-assembled monolayer. This treatment locks in the encapsulated aroma (the "active agent") within a core-shell structure, where the oil represents the core or payload, and the SiO_2 serves as the protective shell. Upon mechanical triggers like abrasion or friction, the capsule wall ruptures, releasing the aroma into the environment.

3.0 Results and Discussion

3.1 Morphology of the nano capsules

In order to study the morphology of nano capsules, nano capsules in sol-gel form, treated fabric and washed fabrics were analyzed by Scanning Electron Microscope (SEM). SEM micrograph of nano capsules, treated fabric and five washed fabric is given in Fig. 8, Fig.9 and Fig.10 respectively. From Fig.8 it can be seen that the nanoparticles are varying in size with a size range of 80 nm to 286 nm. Average majority of the particles are spherical in shape with a size of 116 nm. From Fig 9 it can be seen that the oil nano capsules are embedded on the fabric surface. The size of nano capsules are in the range of 104 nm to 612 nm. Higher the size in treated fabric could be due to agglomeration of nanoparticles on the fabric surface. From Fig.10 it can be seen that the washed fabric (after 5 wash) also contains nano capsules on the surface of fabric. This clearly indicates the presence of oil nano capsules on the surface of washed fabric.

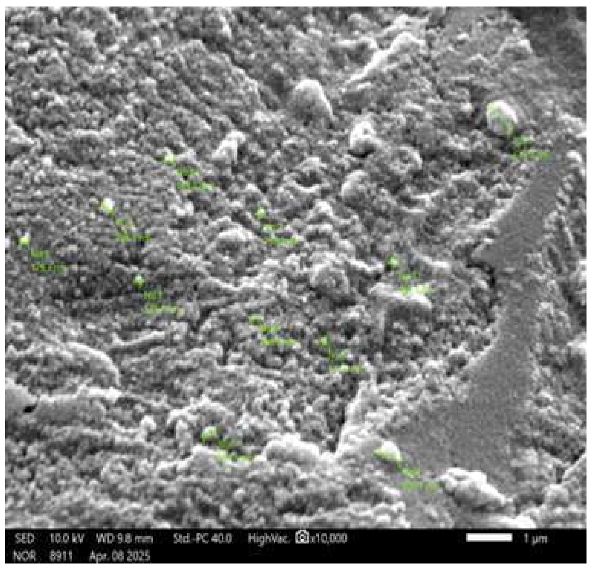


Fig 8 SEM micrograph of sol gel encapsulated essential oil

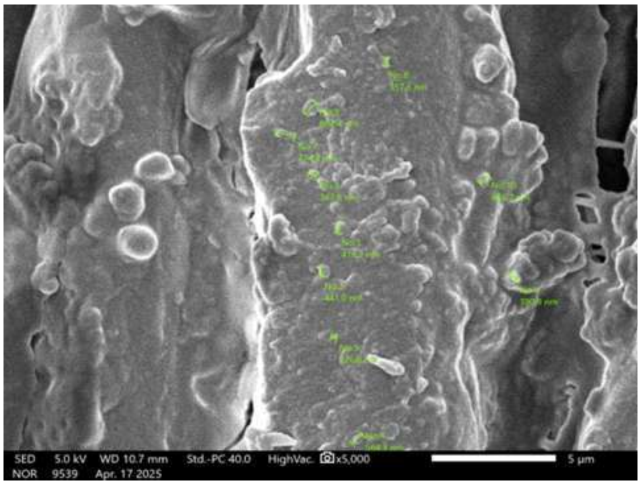


Figure 8. SEM micrograph of encapsulated oil treated fabric

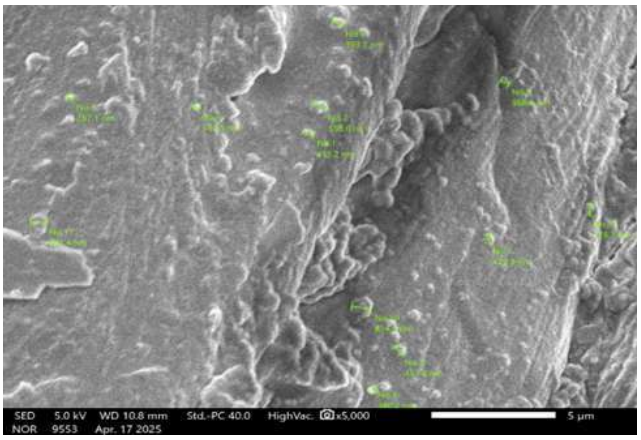


Figure 9. SEM micrograph of encapsulated oil treated fabric

3.2 Wash durability of citronella oil, lavender oil and mixture of citronella oil and lavender oil treated fabric

Citronella essential oil, Lavender essential oil and a mixture of citronella oil and lavender oil treated fabric was subjected to machine wash (front loading washing machine) using 1% detergent at 300C for 15 minutes wash-rinse cycle. The qualitative evaluation of fragrance was assessed by a panel of judgment. Treated fabric and washed fabric was given to a 10 member panel for fragrance rating in the order of 0-5 (No fragrance –very strong fragrance). Average rating of citronella treated fabric and washed fabrics is given in Table 1. The average ratings of panel members for treated fabric and one washed fabric is 5 and 4.7 respectively. This clearly shows that treated fabric is durable to one domestic wash. The washing cycle was repeated further four times and asked the same panel members for their rating. Most of the panel members could detect the fragrance in fabric up to 5th wash cycle with an average rating of 1.0. However, after 5th wash cycle most of the panel members could not sense the presence of fragrance in washed fabric. This indicates that citronella oil treated fabric is durable up to 5 washes. Panel assessment rating of lavender treated fabric and a mixture of citronella and lavender treated and washed fabric is given in Table 2 and Table 3 respectively. From Table 2 it can be seen that all the panel members could sense the fragrance up to the 4th washed fabric. Further, in the 5th and 6th washed fabric a mixture of opinions cropped up within panel members. Similarly from table 3 it can be seen that most of the panel members agree with the presence of fragrances in the washed fabrics up to 5th wash. Further, hardly few members could detect the fragrances in the washed fabrics. From the above observations it is confirmed that essential oil treatment is durable up to 5 washes.

Table 1. Panel assessment for wash durability of citronella oil treated fabric

Panel assessor	Treated fabric	After 1 wash	After 2 wash	After 3 wash	After 4 wash	After 5 wash	After 6 wash
1	5	4	5	3	2	1	0
2	5	5	5	3	2	1	0
3	5	5	5	4	1	1	1
4	5	4	4	3	2	0	0
5	5	4	4	2	1	1	0
6	5	5	5	3	2	1	0
7	5	5	4	4	3	2	1
8	5	5	5	3	1	0	0
9	5	5	4	3	1	2	0
10	5	5	5	3	1	1	0
Mean	5	4.7	4.6	3.1	1.6	1.0	0.2

Table 2 Panel assessment for wash durability of lavender oil treated fabric

Panel assessor	Treated fabric	After 1 wash	After 2 wash	After 3 wash	After 4 wash	After 5 wash	After 6 wash
1	5	4	4	5	3	1	0
2	5	3	4	3	2	1	0
3	5	3	3	4	2	0	0
4	5	4	4	4	3	1	0
5	5	5	2	4	2	0	1
6	5	4	4	3	2	0	0
7	5	5	4	3	4	0	0
8	5	3	3	4	3	1	1
9	5	5	4	3	2	2	0
10	5	5	4	3	1	1	0
Mean	5	4.1	3.6	3.6	2.4	0.7	0.2

Table 3 Panel assessment for wash durability of citronella oil and lavender oil treated fabric

Panel assessor	Treated fabric	After 1 wash	After 2 wash	After 3 wash	After 4 wash	After 5 wash	After 6 wash
1	5	5	5	4	2	2	1
2	5	5	5	5	3	1	1
3	5	4	3	5	2	2	0
4	5	5	4	4	3	1	0
5	5	5	4	3	2	0	0
6	5	4	4	3	1	3	2
7	5	5	3	3	1	2	0
8	5	5	4	2	2	1	0
9	5	5	4	3	1	1	0
10	5	5	3	2	1	1	0
Mean	5	4.8	3.9	3.4	1.8	1.4	0.4

3.3 HS GC MS analysis of citronella oil, Lavender oil and mixture of citronella oil and lavender oil treated and washed fabrics

In order to validate the qualitative panel assessment of treated fabrics and washed fabrics, the same have been quantitatively analyzed by HS GCMS. 10 g each of treated fabrics and washed fabrics were heated at 100oC for 30 minutes in a closed headspace vial of 25 ml capacity and 1.0 ml of the headspace vapors were injected into a GC MS as per the following conditions.

GC MS make and model: Shimadzu GC Nexis 2030, MS QP2020 NX

Column : DB5 MS (30mX0.25mmX0.25µm)

Injector temperature: 250^{0}C

Detector temperature: 260^{0}C

Interface temperature: 270^{0}C

Oven temperature: 40^{0}C,(3 min), @ 8^{0}C,200^{0}C.

Column flow: 1.5 ml/min.

Carrier gas: Helium.

Detected components were identified from the built in NIST library. Area percentage of the major components in the treated fabrics and washed fabrics was calculated and is given in the bar chart from Fig.11 to Fig.13. Fig 11 is the bar chart of major chemical components in citronella treated fabrics and washed fabrics. From Fig. 11 it can be seen that the major components in citronella oil treated fabric is limonene (46%) followed by Citronellal (35%), Geraniol (8.0%), Citral (6.0%) and linalool (5.0%). In each wash cycle, the chemical components gradually decrease till 5th wash. Further in the 6th washed fabric only two components were detected which is also below 3.0%. These data are in agreement to the panel assessment of citronella oil treated and washed fabrics.

Fig.12 is the bar chart representing major chemical components in lavender oil treated fabric and washed fabrics. From Fig.9 it can be seen that the major chemical components in lavender oil treated fabric is linalool (44%), followed by linalyl acetate (41%), lavandulyl acetate (2.0%) and limonene (2.0%). At the end of 5th wash, only two components were detected which is linalool and linalyl acetate of 5.0% each. Further in the 6th washed fabric linalool and linalyl acetate detected is below 1.0%. This data is also in agreement with the panel judgments of lavender oil treated and washed fabrics.

Fig.13 is the bar chart representing major chemical components in a mixture of citronella and lavender oil treated and washed fabrics. From Fig.10 it can be seen that major components in the citronella oil and lavender oil treated fabric is linalool (33%), followed by linalyl acetate (32%), Citronellal (16%), Geraniol (3%) and lavandulyl acetate (2%). In each wash cycle the fragrance components diminishes and at the end of 5th wash cycle three major components detected were linalyl acetate (9.5%), linalool (9.0%) and Citronellal (4.0%). However, in the 6th wash cycle, components detected are linalyl acetate (3.0%), Citronellal (1.2%), and linalool (0.3%). This data is also in agreement with the panel judgments.

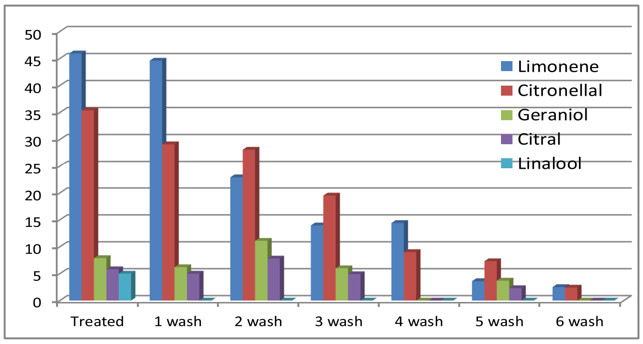


Figure 11 - Wash durability of citronella oil treated fabric

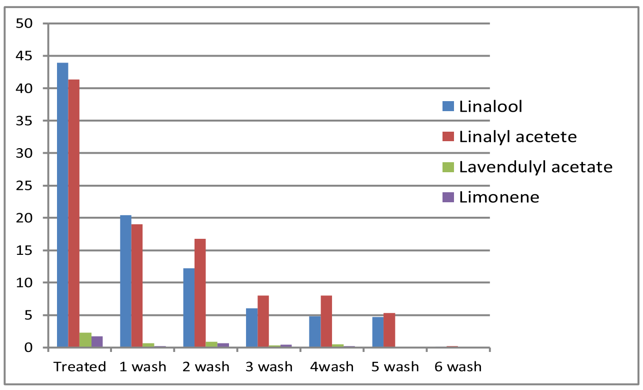


Figure 12 - Wash durability of Lavender oil treated fabric

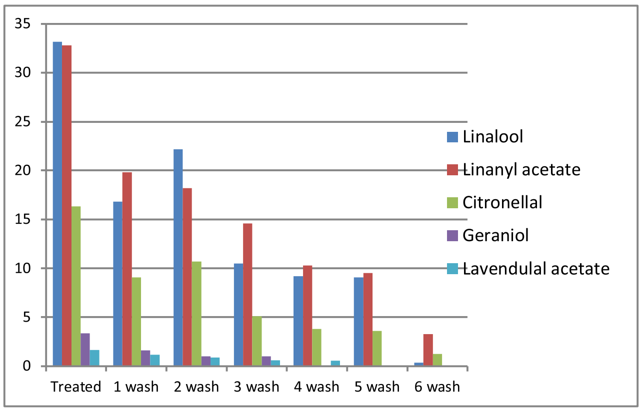


Figure 13 wash durability of Citronella and lavender oil treated fabric

3.4 Field trials

User trials are crucial to evaluate overall product performance. 25 treated pillow covers along with pillows were supplied to Janiv Ashram, an old age home situated in Kharad village, Thane district. After using the pillows for one month a feedback was sought from the inmates of the Ashram. Each inmate was asked to fill up the feedback questionnaire about the mosquito repellant property, comfort level, sleep quality, wash durability etc. Majority of the inmates opined that the pillow has a pleasant smell and lasts for a couple of washes. All the inmates agree that while using these pillows no mosquitoes enter the bed room. Few inmates reported that by using these pillows their sleep quality improved. Fig.14A and 14B are the photographs of Janiv Ashram where the field study was conducted.

4. Conclusions

Fragrance compounds present in essential oils are inherently volatile, making it challenging to retain their aroma on textile substrates over extended periods. One of the primary difficulties in developing fragrance-emitting fabrics is prolonging the olfactory lifespan of the applied aroma Nano-encapsulation offers a promising solution to this issue by controlling the release of volatile compounds. By incorporating essential oils into nanostructured carriers, the storage stability and wash durability of aroma-functional textiles can be significantly improved. Nano encapsulated citronella oil and lavender oil applied on cotton fabric is found to be durable up to 5 washes. In this study, lavender oil and citronella oil were successfully encapsulated with sol-gel technique. Synthesized Nano capsules were in the size range of 80 nm to 286 nm. These Nano capsules can be applied on to cotton fabric by a simple spray dry process. HS GC /MS analysis of treated and washed fabrics shows treated fabrics are durable up to five laundry washes. The same has been confirmed by panel members by assessing the fragrance. A feedback obtained from the user panel reveals that citronella and lavender oil treated pillow covers have a good mosquito repellent property with a pleasant fragrance. The treated pillow covers are durable up to five washes. The same has been validated by HS GC/MS analysis by measuring the fragrance intensity. Hence, home textiles such as curtains, table cloths, sofa covers, sheets etc. which are not required for frequent laundering may be applied with Nano encapsulated citronella and lavender oil.

Fig.14 A Janiv Ashram entrance

Fig.14 B Residence of inmates

Conflict of Interest

Authors hereby declare that there is no conflict of interest in publication of this paper. All the data generated and presented in this paper is based on this project work and is authentic.

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References

1. Heitor Luiz Ornaghi Júnior, Roberta Motta Neves, Francisco Maciel Monticeli, Lucas Dall Agnol, Smart Fabric Textiles: Recent Advances and Challenges, Textiles,2022, 2, 582–605.
2. Sunidhi Mehta, Maureen Mac Gillivray, Aromatherapy in Textiles: A Systematic Review of Studies. Examining Textiles as a Potential Carrier for the Therapeutic Effects of Essential Oils, Textiles,2022, 2, 29–49.
3. Faiza Anwar, Mudassar Abbas, Mumtaz Hasan Malik, Amna Aziz Cheema, Suniya Tariq, Warda Afzal and Asfandyar Khan, Development of Mosquito-Repellent Camouflage Fabric Using Eucalyptus Oil with Moringaoleifera Gum, Chem. Engg.,2023, 7, 64.
4. Da-Som Kim, Seong-Jun Hong, Sojeong Yoon, Seong-Min Jo, Hyangyeon Jeong, Moon-YeonYoun, Young-Jun Kim, Jae-Kyeom Kim,Eui-Cheol Shin, Olfactory Stimulation with Volatile Aroma Compounds of Basil (Ocimumbasilicum L.) Essential Oil and Linalool Ameliorates White Fat Accumulation and Dyslipidemia in Chronically Stressed Rats, Nutrients,2022, 14, 1822.
5. Na-Yoon Choi, Yu-Tong Wu, Sin-Ae Park, Effects of Olfactory Stimulation with Aroma Oils on Psychophysiological Responses of Female Adults, Int. J. Environ. Res. Public Health 2022, 19, 5196.
6. Kutlu, A.K.; Yilmaz, E.; Cecen, D. Effects of aroma inhalation on examination anxiety. Teach. Learn. Nurs. 2008, 3, 125–130.
7. Touhara, K.; Vosshall, L.B. Sensing odorants and pheromones with chemosensory receptors. Annu. Rev. Physiol. 2009, 71, 307–332.
8. Vânia Isabel Sousa, Joana Filipa Parente , Juliana Filipa Marques, Marta Adriana Fortemand Carlos José Tavares, Microencapsulation of Essential Oils: A Review, Polymers2022, 14, 1730.
9. Douglas Rodrigues Reis, Alan Ambrosi, Marco Di Luccio, Encapsulated essential oils: A perspective in food preservation, Future Foods, 2022, 5, 100126.
10. Touré, A., Lu, H. B., Zhang, X & Xueming, . Microencapsulation of Ginger Oil in 18DE Maltodextrin/Whey Protein Isolate. J. Herbs, Spices & Medicinal Plants, 2011, 17(2), 183–195.
11. Xiongyi Peng, Muhammad Umer, Md. Nahid Pervez, K.M. Faridul Hasan, Md Ahsan Habib, Md. Shahinoor Islam, Lina Lin, Xiaorong Xiong, Vincenzo Naddeo, Yingjie Cai, Biopolymers-based microencapsulation technology for sustainable textiles development: A short review, Case Studies in Chem. Env. Engg. 2023, 7, 100349.
12. M P Sathianarayanan, Karishma Hemani, Development of bio degradable cotton waste based super oleophilic and super hydrophobic sorbent for oil spill clean- up, J. Institution of Engineers, India,2021.

A Review on Cutting-Edge Utilization of UHMWPE Polymer in Industrial and Medical Applications

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Abstract
This review focuses on "ultra-high molecular weight polyethylene (UHMWPE), a high-performance polymer used in medical and industrial applications. UHMWPE shows high-performance characteristics such as high mechanical strength, excellent wear resistance, and biocompatibility. In the case of industrial applications, UHMWPE is specifically used in automotive, marine, and mining. In contrast, in the case of aerospace applications, it is used for parts like gears, bearings, ropes, cables, and conveyor belts owing to its low coefficient of friction, superior wear resistance, and high impact strength. UHMWPE composites are nowadays more promising for use in aerospace, making light parts, and protecting against bullets, which are addressed in this article. In the medical field, UHMWPE is widely accepted as an orthopedic implant for its biocompatibility and resistance to wear. It is primarily used in hip and knee arthroplasty, where it serves as an acetabular liner and tibial insert. UHMWPE has also been studied for its use in heart devices, drug delivery systems, and dental tools. Researchers are working to make UHMWPE better, and methods for improvements like cross-linking, adding tiny particles, and treating the surface. "These efforts aim to make implants work better and last longer by solving problems like wear-related bone loss or osteolysis. This paper also discusses the increasingly recognized potential of UHMWPE, leading to its growing industrial and medical applications.

Key words:
UHMWPE, industrial applications, medical applications, orthopedic implants, wear resistance, biocompatibility

Citation
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1. Introduction:

Ultra-high molecular weight polyethylene (UHMWPE) is one of the high-performing polymers that has outstanding tensile or mechanical characteristics, wear resistance, and biocompatibility [1]. In the industrial sector, UHMWPE is used in various applications in shipbuilding, the textile industry, and also in biomedical areas such as implantable devices for complete joint endoprostheses [2][3][4].There has been an impressive history of UHMWPE development over the years, from the historic gamma air-sterilized polyethylene to the new 1st and 2nd generation highly crosslinked products, all designed to improve performance [4]. In the 1990s, new methods like using irradiation in a nitrogen atmosphere and special packaging were used wherein this led to the creation of the first type of crosslinked polyethylene [2]. Recent studies have focused on solving problems related to oxidation and material damage. As a result, new types of polyethylene have been developed, including highly cross-linked polyethylene and polyethylene with vitamin E [2][5]. The significance of UHMWPE in both industrial and medical sectors is considerable. In the medical domain, it is particularly utilized in total joint arthroplasties, including acetabular liners or sockets for total hip replacements and tibial inserts for total knee replacements [6]. Their low friction, good wear resistance, and ability to resist chemicals make them useful in many industries [3]. Current research and development efforts in ultra-high-molecular-weight polyethylene (UHMWPE), particularly in the areas of processing techniques such as precipitation polymerization and additive manufacturing, are continually enhancing its potential applications and improving its performance in both industrial and medical sectors [5][6][7]. UHMWPE has improved over time, and now, third-generation materials are being made to make it stronger and more resistant to oxidation [8]. These improvements include new ways to link materials, adding antioxidants, and changing surfaces to make them last longer and lower the chance of implant failure [8][9]. As research advances, there is an increasing interest in investigating the potential of UHMWPE nanocomposites, which may offer improved mechanical strength and tribological properties for both industrial and biomedical applications [10].

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2. Fundamental Properties of UHMWPE

UHMWPE comprises long chains of simple polyethylene molecules, as shown in Figure 1, where "n" denotes the degree of polymerization, which varies from 36,000 to 110,000 [1]. Regarding the long molecular chain and the corresponding high molecular weight, the result is very strong and durable with exceptional properties [4][7]. Such properties are high mechanical properties, including high strength, excellent wear resistance, and low friction coefficient [11][12]. These properties also make it an ideal material for artificial joints and other load-bearing applications. The material has a very good resistance to chemicals and is safe for use in medical implants due to its biocompatibility [1][3]. In other words, UHMWPE is characterized by a low melting point and a high melt viscosity, which makes it challenging to process. This often necessitates specialized techniques such as powder processing and sintering [3]. For biocompatibility, UHMWPE has demonstrated exceptional performance as an artificial joint replacement, with 15-20 year durability [12]. However, ongoing research is needed to improve long-term performance due to the generation of wear debris or residual UHMWPE particles during use, which can lead to adverse interactions with the surrounding tissue [4][12]. Current research endeavors are concentrated on further enhancing these properties to prolong the lifespan of UHMWPE-based implants and improve their overall performance [1][13].

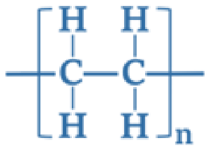


Figure 1: Molecular structure of UHMWPE

3. Industrial Applications

A. Automotive industry

As discussed above, UHMWPE is known for its high wear resistance, low friction coefficient, and excellent mechanical properties [1][12],it can be used in different industrial applications where durability and low friction are crucial. Furthermore, UHMWPE exhibits high impact resistance, which enhances its value in industrial applications.However, its processing can be challenging [14]. In contrast to the previously mentioned facts, Khalil et al. (2019) observe that UHMWPE-based products are very tough to produce by conventional methods such as injection molding and extrusion due to their ultra-high melt viscosity or almost zero flow rate at melting or higher temperatures [15][16]. This limitation may hinder the broader industrial automotive sector,which requires complex geometries or large-scale manufacturing.

B. Marine industry

In the marine industry, UHMWPE-based components are used in applications such as warps and hand ropes for large mid-water trawls in fisheries, as well as in cables and anchor ropes for net cages in large-scale mariculture [17]. Furthermore, this polymer is extensively utilized in shipbuilding due to its low coefficient of friction, superior abrasion resistance, and exceptional chemical resistance [3]. Apart from its different advantages, it has a low thermal stability and low load-bearing capacity [11], which may restrict its use in certain high-stress marine components. To address this challenge, researchers have explored the reinforcement of ultra-high-molecular-weight polyethylene (UHMWPE) with materials such as graphene nanoplatelets to improve its tribological properties and expand its applications in mechanical bearing systems [11].

C. Mining and heavy machinery

UHMWPE can be used in the manufacture of mining and heavy equipment components and accessories due to its excellent wear resistance, low coefficient of friction, and high impact strength [18][19]. And based on the aforesaid properties, UHMWPE may be suitable for conveyor belts, linings, wear plates, and chute linings in harsh mining environments. In addition, recent studies have shown that the mechanical properties and wear behavior of UHMWPE compound can be enhanced by the integration of short carbon fibers (CF) through the preparation of composites [20]. It was found that the compressive modulus and hardness increased as the fiber content increased, whereasthe friction coefficient and wear rate decreased.Furthermore, surface-treated CF with nitric acid resulted in a further improvement of the interfacial adhesion between CF and UHMWPE, resulting in superior mechanical and tribological properties. In this regard, another study has shown that glass fiber can be reinforced with UHMWPE, where glass fiber-based UHMWPE composites have been produced for use as liner sheets to protect ships, construction vehicles, and transportation equipment [21]. This study determined that the mechanical and tribological properties of the composites are highly influenced by the initial size of the powder and the length of the glass fibers.

D. Aerospace and ballistic applications

Ultra-high molecular weight polyethylene (UHMWPE) composites have shown improvement in various mechanical properties as discussed above. Moreover, the material has great potential in the aerospace sector, particularly for lightweight structural components, high strength-to-weight ratio, and ballistic protection [22]. In this context, Figure 2 presents the difference between various materials based on their density and strength.

One of the studies indicated that "UHMWPE composites exhibit superior mass efficiency compared to conventional metallic and composite armor materials in resisting fragments simulating projectiles [23]. In the case of ballistic protection, UHMWPE fabrics integrated with Energy Absorption Materials and Structures (EAMS) have been shown to reduce backface signature values by 6-17% compared to pure UHMWPE panels with equivalent areal density [24].Compared to other laminate structures, unidirectional UHMWPE composite laminates exhibit superior ballistic velocity and energy absorption per unit

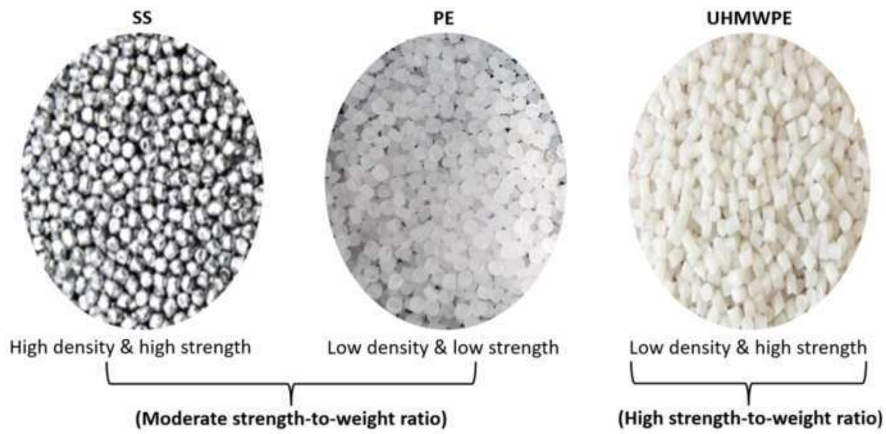


Figure 2: Various materials showing strength-to-weight ratio based on density and strength

weight [25].Here, it is better to say the entire composite can be affected by fiber type, fabric structure, and orientation of fabric layers.

4. Medical Applications

A. Orthopedic implants

Ultra-high molecular weight polyethylene (UHMWPE) is extensively utilized in orthopedic implants, particularly in hip and knee replacements, owing to its superior properties, including high wear resistance, biocompatibility, and chemical stability [1][6]. In total hip arthroplasty, ultra-high-molecular-weight polyethylene (UHMWPE) is frequently employed as acetabular liners or sockets, whereas in total knee arthroplasty, it functions as tibial inserts [6]. UHMWPE's performance in hip implants depends on the chemical and mechanical conditions in the implant environment that may change its properties over time. For example, UHMWPE hip cups may experience density increase and oxidative chain degradation [26]. In this context, the material for the selection of the femoral head plays a crucial role in determining wear rates. Conventional UHMWPE can be combined with ceramic heads consisting of alumina or cobalt chromium, and alumina-based heads effectively reduce wear rates more than cobalt chromium [27][28]. Several modifications have been investigated to improve the performance of UHMWPE in orthopedic applications. Among these, irradiation crosslinking has shown much lower wear rates than conventional UHMWPE [28]. UHMWPE may also be enhanced with nanoparticles, including zirconium oxide, to increase both mechanical and biological attributes [29]. In addition, the surface hardness can be improved by surface modification, including nitrogen plasma immersion ion implantation [30]. These improvements were designed to address UHMWPE implant challenges, such as wear-related osteolysis, and to improve overall implant durability and lifetime.

B. Cardiovascular devices, drug delivery systems and dental applications

Ultra-high-molecular-weight polyethylene is used in many heart devices, like parts of the heart valves and vascular grafts, or blood vessel replacements. It is also used in systems that deliver medicine, or as a drug delivery system, and in dental applications. In cardiovascular applications, UHMWPE tissue-engineered cardiovascular grafts (TECVG) have demonstrated potential as a viable alternative to conventional prosthetic grafts. These TECVGs show promising results for growth, longevity, and infection resistance, with no indication of rejection problems [31]. UHMWPE is also being used as a platform for cardiovascular drug delivery systems, where researchers have developed scaffolds integrated with growth factors, cytokines, and drugs to facilitate the targeted and local delivery of drug molecules [31]. Although UHMWPE is widely used in orthopedic applications, its use in cardiovascular devices has rarely been documented in the available literature. However, the ability to deliver vascular endothelial growth factor (VEGF) to UHMWPE surfaces using silk fibroin coating has shown improved bone-to-implant integration, with potential cardiovascular applications [32].

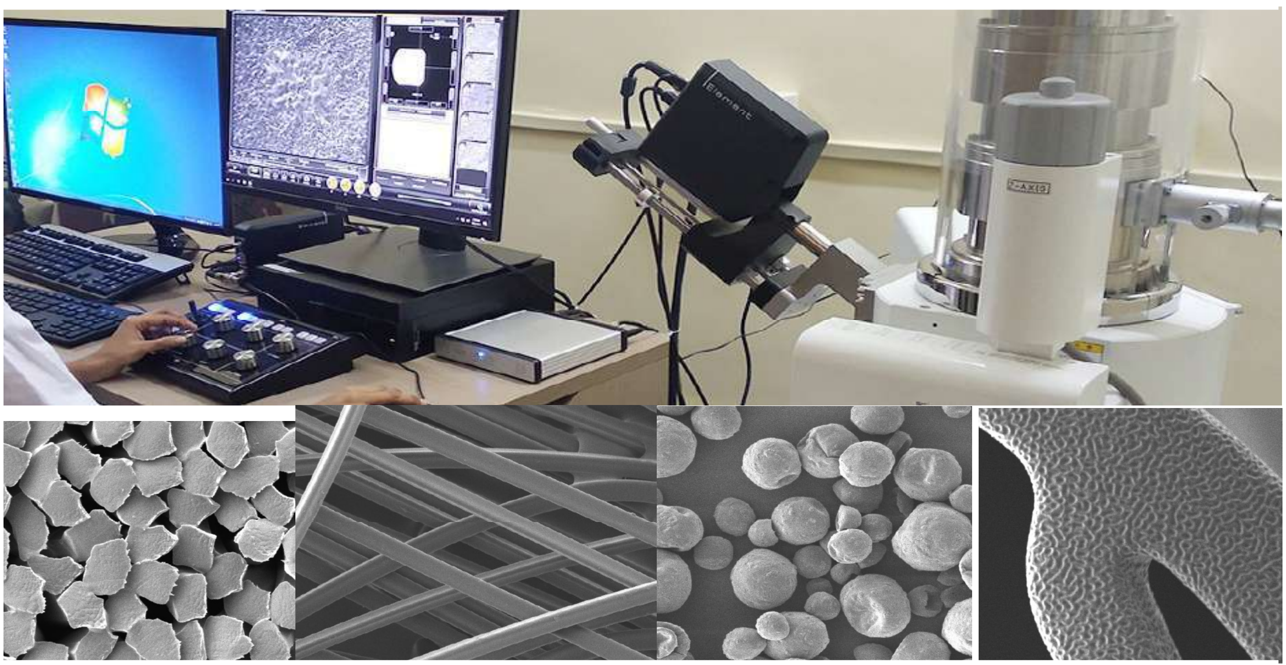
5. Conclusions

This work effectively discussed the high-performance polymer, ultrahigh molecular weight polyethylene, with applications in both the industrial and medical domains. The characteristics of UHMWPE, such as its tensile or mechanical properties, biocompatibility, and resistance to various chemicals, are well discussed in this paper. It is utilized in various industrial sectors, including the automotive, marine, mining, and aerospace industries. Its suitability for components like gears, bearings, ropes, cables, and conveyor belts owing its low friction coefficient, excellent wear resistance, and strong impact strength. In the aerospace industry, UHMWPE composites have demonstrated potential for use in lightweight structural parts and ballistic protection. UHMWPE has been particularly advantageous in the medical sector, notably in orthopedic implants such as hip and knee replacements. Due to its biocompatibility and wear resistance, this material is preferred for use in acetabular liners and tibial inserts.

References

1. M. Hussain et al., "Ultra-High-Molecular-Weight-Polyethylene (UHMWPE) as a Promising Polymer Material for Biomedical Applications: A Concise Review," Polymers, vol. 12, no. 2, p. 323, Feb. 2020, doi: 10.3390/polym12020323.
2. E. Gomez-Barrena, J.-A. Puertolas, L. Munuera, and Y. T. Konttinen, "Update on UHMWPE research From the bench to the bedside," Acta Orthopaedica, vol. 79, no. 6, pp. 832–840, Jan. 2008, doi: 10.1080/17453670810016939.
3. S. Hambir and J. P. Jog, "Sintering of ultra high molecular weight polyethylene," Bulletin of Materials Science, vol. 23, no. 3, pp. 221–226, Jun. 2000, doi: 10.1007/bf02719914.
4. P. Bracco, A. Bellare, S. Affatato, and A. Bistolfi, "Ultra-High Molecular Weight Polyethylene: Influence of the Chemical, Physical and Mechanical Properties on the Wear Behavior. A Review.," Materials, vol. 10, no. 7, p. 791, Jul. 2017, doi: 10.3390/ma10070791.
5. W. Duan, M. Wu, J. Han, and Z. Ni, "Research into the thermal stability and mechanical properties of vitamin E diffusion modified irradiation cross-linked graphene oxide/ultra-high molecular weight polyethylene composites.," RSC advances, vol. 10, no. 8, pp. 4175–4188, Jan. 2020, doi: 10.1039/c9ra09893c.
6. V. Sharma, S. Chowdhury, N. Keshavan, and B. Basu, "Six decades of UHMWPE in reconstructive surgery," International Materials Reviews, vol. 68, no. 1, pp. 46–81, May 2022, doi: 10.1080/09506608.2022.2047419.
7. W. Wang, Q. Wang, C. Zou, and C. Chen, "Synthesis of Ultra-High-Molecular-Weight Polyethylene by Transition-Metal-Catalyzed Precipitation Polymerization.," Precision chemistry, vol. 2, no. 2, pp. 63–69, Jan. 2024, doi: 10.1021/prechem.3c00103.
8. X. Li, F. Yue, W. Pang, J. Wu, and B. Kong, "Mechanical and wear properties of GO-enhanced irradiated UHMWPE with good oxidation resistance," Fullerenes, Nanotubes and Carbon Nanostructures, vol. 27, no. 5, pp. 459–467, May 2019, doi: 10.1080/1536383x.2019.1608437.
9. E. Perez, P. Corengia, B. Parodi, E. D. L. Heras, L. Pazos, and I. Braceras, "Wear Behaviour of UHMWPE Against DC-Pulsed Plasma Nitrided and Duplex Treated AISI 316L Used in Hip Joint Replacements," Plasma Processes and Polymers, vol. 6, no. S1, pp. S75–S80, Apr. 2009, doi: 10.1002/ppap.200930306.
10. A. Vinoth, R. Khedar, S. Datta, and K. N. Nirmal, "Optimizing the Tribological Properties of UHMWPE Nanocomposites—An Artificial Intelligence based approach," springer singapore, 2020, pp. 831–843. doi: 10.1007/978-981-15-4488-0_70.
11. I. K. Aliyu, A. S. Mohammed, and A. Al-Qutub, "Tribological performance of ultra high molecular weight polyethylene nanocomposites reinforced with graphene nanoplatelets," Polymer Composites, vol. 40, no. S2, pp. E1301–E1311, Aug. 2018, doi: 10.1002/pc.24975.
12. J. Baena, Z. Peng, and J. Wu, "Wear Performance of UHMWPE and Reinforced UHMWPE Composites in Arthroplasty Applications: A Review," Lubricants, vol. 3, no. 2, pp. 413–436, May 2015, doi: 10.3390/lubricants3020413.
13. J. Fu et al., "Natural polyphenol-stabilised highly crosslinked UHMWPE with high mechanical properties and low wear for joint implants.," Journal of Materials Chemistry B, vol. 1, no. 37, p. 4727, Jan. 2013, doi: 10.1039/c3tb20707b.
14. A. Nawaz Khan, M. Gupta, P. Mahajan, A. Das, and R. Alagirusamy, "UHMWPE textiles and composites," Textile Progress, vol. 53, no. 4, pp. 183–335, Aug. 2022, doi: 10.1080/00405167.2022.2087400.
15. H. Zhang and Y. Liang, "Extrusion Processing of Ultra-High Molecular Weight Polyethylene," institute for new technologies, 2018. doi: 10.5772/intechopen.72212.
16. Y. Khalil, N. Hopkinson, A. Kowalski, and J. P. A. Fairclough, "Characterisation of UHMWPE Polymer Powder for Laser Sintering," Materials, vol. 12, no. 21, p. 3496, Oct. 2019, doi: 10.3390/ma12213496.
17. G. Han, X. Li, X. Tao, W. Jiang, and W. Zuo, "Study of the Mechanical Properties of Ultra-High Molecular Weight Polyethylene Fiber Rope," Journal of Engineered Fibers and Fabrics, vol. 11, no. 1, p. 155892501601100, Mar. 2016, doi: 10.1177/155892501601100103.
18. S. Liao, M. Wu, X. Mao, Y. Wang, and Z. Wang, "The injection molding of large industrial ultrahigh molecular weight polyethylene products: A microbeam WAXD/SAXS investigation of the impaction of bimodal polyethylene on the structure and mechanical properties," Polymer, vol. 317, p. 127950, Jan. 2025, doi: 10.1016/j.polymer.2024.127950.
19. C. Yang, J. Zhang, X. Kang, and H. Yue, "The Low Friction Coefficient and High Wear Resistance UHMWPE: The Effect of Pores on Properties of Artificial Joint Materials," Lubricants, vol. 13, no. 1, p. 31, Jan. 2025, doi: 10.3390/lubricants13010031.
20. Q. Wang, Y. Wang, H. Wang, and F. Yan, "Modification effects of short carbon fibers on mechanical properties and fretting wear behavior of UHMWPE composites," Surface and Interface Analysis, vol. 48, no. 3, pp. 139–145, Dec. 2015, doi: 10.1002/sia.5921.
21. S. V. Panin et al., "Effect of Adhesion on Mechanical and Tribological Properties of Glass Fiber Composites, Based on Ultra-High Molecular Weight Polyethylene Powders with Various Initial Particle Sizes.," Materials, vol. 13, no. 7, p. 1602, Apr. 2020, doi: 10.3390/ma13071602.

22. T. Xu and R. J. Farris, "Comparative studies of ultra high molecular weight polyethylene fiber reinforced composites," Polymer Engineering & Science, vol. 47, no. 10, pp. 1544–1553, Sep. 2007, doi: 10.1002/pen.20876.
23. L. H. Nguyen, S. Ryan, A. P. Mouritz, S. J. Cimpoeru, and A. C. Orifici, "The Efficiency of Ultra-High Molecular Weight Polyethylene Composite Against Fragment Impact," Experimental Mechanics, vol. 56, no. 4, pp. 595–605, Jun. 2015, doi: 10.1007/s11340-015-0051-z.
24. X. Liu et al., "Ballistic performance of UHMWPE fabrics/EAMS hybrid panel," Journal of Materials Science, vol. 53, no. 10, pp. 7357–7371, Jan. 2018, doi: 10.1007/s10853-018-2055-4.
25. M. Karahan, A. Jabbar, and N. Karahan, "Ballistic impact behavior of the aramid and ultra-high molecular weight polyethylene composites," Journal of Reinforced Plastics and Composites, vol. 34, no. 1, pp. 37–48, Dec. 2014, doi: 10.1177/0731684414562223.
26. M. Kurth, P. Eyerer, U. Holz, K. Dittel, and R. Ascherl, "An evaluation of retrieved UHMWPE hip joint cups.," Journal of Biomaterials Applications, vol. 3, no. 1, pp. 33–51, Jan. 1988, doi: 10.1177/088532828800300102.
27. M. N. Rahaman, M. D. Ries, J. P. Garino, A. Yao, and B. S. Bal, "Ceramics for Prosthetic Hip and Knee Joint Replacement," Journal of the American Ceramic Society, vol. 90, no. 7, pp. 1965–1988, Jul. 2007, doi: 10.1111/j.1551-2916.2007.01725.x.
28. T. Sato et al., "Wear resistant performance of highly cross-linked and annealed ultra-high molecular weight polyethylene against ceramic heads in total hip arthroplasty," Journal of Orthopaedic Research, vol. 30, no. 12, pp. 2031–2037, May 2012, doi: 10.1002/jor.22148.
29. M. Salari, M. A. Faghihi Sani, S. Mohseni Taromsari, and R. Bagheri, "Improved wear, mechanical, and biological behavior of UHMWPE-HAp-zirconia hybrid nanocomposites with a prospective application in total hip joint replacement," Journal of Materials Science, vol. 54, no. 5, pp. 4259–4276, Nov. 2018, doi: 10.1007/s10853-018-3146-y.
30. A. R. Marcondes et al., "Improvements of ultra-high molecular weight polyethylene mechanical properties by nitrogen plasma immersion ion implantation," Brazilian Journal of Physics, vol. 34, no. 4b, pp. 1667–1672, Dec. 2004, doi: 10.1590/s0103-97332004000800029.
31. C. Spadaccio, M. Trombetta, J. A. Genovese, M. Chello, A. Rainer, and Y. Toyoda, "Drug releasing systems in cardiovascular tissue engineering," Journal of Cellular and Molecular Medicine, vol. 13, no. 3, pp. 422–439, Oct. 2008, doi: 10.1111/j.1582-4934.2008.00532.x.
32. C. Ai et al., "Surface modification of vascular endothelial growth factor-loaded silk fibroin to improve biological performance of ultra-high-molecular-weight polyethylene via promoting angiogenesis.," International Journal of Nanomedicine, vol. 12, no. 5, pp. 7737–7750, Oct. 2017, doi: 10.2147/ijn.s148845.



Biosynthesized Silver Nanoparticles as Antimicrobial Finish over Cotton Fabric

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Abstract
This paper describes the use of the bioreduction process to synthesize silver nanoparticles (AgNPs). The aqueous extract of Tabernaemontana divaricta (pinwheel flower) and silver nitrate, which serve as a reducing agent and precursor salt, respectively, have been used in the synthesis of AgNPs. Using scanning electron microscopy and UV-visible spectroscopy, synthesized AgNPs have been characterized.The optical characteristics of AgNPs were assessed using UV-visible spectroscopy by means of the Surface Plasmon resonance (SPR) peak. This SPR peak appeared at 410 nm and suggested an average particle size of 40 to 60 nm. Using SEM examination, the AgNPs' morphology was investigated. Using the Continuous Pad-Dry-Cure technique, these synthesized AgNPs were applied to cotton fabric. AgNP-deposited fabricswere then evaluated in terms of antibacterial activity and wash durability. The developed AgNP-deposited cotton fabric showed excellent antibacterial activity up to 10 numbers of soap washes.

Key words:
Silver Nanoparticles, Tabernaemontana divaricta (Pinwheel) flower extract, bioreduction, cotton, antibacterial, wash durable.

Citation
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1.0 Introduction

The study of structures and substances with sizes between one and one hundred nanometres is known as nanotechnology. In nanometer size, structures have different properties (such as electrical, optical, thermal, and mechanical) than in macroscale or bulk scale [1,2]. In nanomaterials, properties differ based on the way molecules and atoms assemble on the nanoscale into larger structures based on quantum mechanical effects [2,3]. Nanotechnology can be usedin various fields such as nano-medicines [4,5], biomedical applications (to treat diseases or prevent health issues) [6], industrial applications (including construction materials, military goods, etc[7,8] , water purification, effluent treatment, etc [8]. Various physical and chemical methods can be used to prepare nanoscale materials having different sizes and shapes [9]. However high cost and involvement of toxic chemicals in the synthesis process limit the advantages and uses of these nanoparticles [10 ,11]. Biological procedures can overcome this problem by adopting the easy, nontoxic and environment-friendly methodology [12, 13]. Plant extract-based nanoparticles synthesis have drawn interest recently due to their ease of use and affordability. Sukumaran S et al. reported the antibacterial properties of Peltophorumpterocarpum (DC) flower extract [14]. Hassan Mahmoodi Esfanddarani et al. attained the biosynthesis of metal silver nanoparticles by using Malva sylvestris flower extract as reducing agent and nanoparticle antibacterial properties tested against Escherichia coli (E. coli), Staphylococcus aureus (S. aureus), Streptococcus pyogenes (S. pyogenes) using the disk diffusion assay [15]. The preparation of biosynthesized silver nanoparticles by lemon fruit extract and their potential application as antifungal finishes was explored by Vankar P. et al [16].

In this work, the water-based extract of Tabernaemontana divaricta flower (pinwheel flower) was utilized in the preparation of the silver nanoparticles. This extract acts as both an encapsulating agent and a reducing agent. UV-visible spectroscopy and SEM analysis were used to determine the size of synthesised nanoparticles. Prepared biosynthesized AgNPs applied on cotton fabric through pad-dry-cure process, to provide a wash durable antimicrobial finish. The treated textiles have shown remarkable antibacterial qualities. As far as we know, there haven't been any reports of using Tabernaemontana divaricta (pinwheel) flower extract for AgNP synthesis. Accordingly in this work synthesis, characterization, and application of AgNPs are reported using Tabernaemontana divaricta-(Pinwheel) Flowers extract.

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2.0 Experimental

2.1 Materials:

Silver Nitrate was used as the initial silver ion source in the synthesis and it was procured from Merck India PVT Ltd. Tabernaemontana divaricta-Pinwheel Flowers(Figure 1) were freshly collected from the campus of Bombay Textile Research Association (BTRA) Mumbai, Maharashtra, India from the Garden area. The synthesis used this flower extract as a reducing agent.

Figure.1 Tabernaemontana divaricta flower (pinwheel flower)

2.2 Preparation of flower extract

In a 250 ml glass beaker about 18 to 20 numbers of thoroughly washed pinwheel flowers(weighing approximately 4.5g), were taken and heated(up to boiling) for 10 minutes with hundred milliliters of deionized water. The resulting solution was then used as a bio extract for synthesis after being filtered via filter paper number 42.

2.3 Qualitative screening for phytochemicals

Standard techniques were used to qualitatively screen flower extract for the presence of alkaloids, phenolic chemicals, flavonoids, terpenoids, and tannins [12, 17]. Two millilitres of flower extract and one millilitre of Wagner's reagent were placed in a test tube for the purpose of detecting alkaloids. Alkaloids are present when a reddish-brown precipitate forms after adding Wagner's reagent. By adding a few drops of a 1% sodium hydroxide solution, flavonoids were found. The presence of flavonoids is indicated by the colour turning yellow immediately. Presence or absence of Tannins and Terpenoids were analysed using the ferric chloride test and Salkowaski test respectively. The formation of greenish black precipitate with ferric chloride addition in extract indicates the presence of Tannins. After carefully mixing 5 milliliters of extract with 2 millilitres of chloroform and 3 milliliters of strong sulphuric acid, the development of reddish-brown color indicates the presence of terpenoids. Presence of phenolic compounds was identified by ferric chloride test.

2.4 Synthesis of silver nanoparticles using bio extract:

With continuous stirring, five millilitres of the produced pinwheel flower extract were added to fifty millilitres of 0.001 millilitres of $AgNO3$ solution. To optimize the effects of the silver nanoparticles, the entire solution was kept at 90°C in a dark condition in water bath .The colour of the silver nitrate solution gradually changes from colourless to yellowish brown as the formation of silver nanoparticles proceeds (Figure 2).

Fig.2 Biosynthesized AgNPs using Pinwheel flower extract

2.5 Application of bio-synthesised silver nanoparticles to cotton fabric

The 3dip-3nip method is used to apply biosynthesized silver nanoparticles to cotton fabric, which are then dried and cured. Fabrics deposited with these nanoparticles were examined further for their antibacterial properties and washability. To analyse the wash durability of finished fabric, the ISO 6330 washing method is used and after washing ,durability measured in terms of antimicrobial activity. Antimicrobial activity of AgNP-deposited fabric was measured using AATCC-100 standard test method against staphylococcus aureus (SA) and Klebsiella pneumonia (Kp).

3.0 Characterisation of synthesized silver nanoparticles

3.1 Optical properties

The Schimadzu UV-visible Spectrophotometer model (UV-1800) was used to assess the optical characteristics of silver nanoparticles in the 200–800 nm range by observing the appearance of a surface resonance peak.

3.2 FTIR Investigation

The functional groups responsible in reducing Ag^+ ions to AgNPs were identified using FTIR analysis. The Pinwheel flower extract and related AgNPs' FTIR spectra were measured in the 600–4000 cm-1 range using the Perkin Elmer Miracle ATR-spectrum-2 FTIR spectrometer.

3.3 SEM Analysis

The size and shape of the generated silver nanoparticles were examined using a scanning electron microscope. The JEOL JSM IT 200 was used to capture scanning electron micrographs in order to examine the surface morphology of the biosynthesised AgNPs.

4. Results and discussion

4.1 Phytochemical Screening Evaluation

Table 1 displays the findings of the initial phytochemical screening of the pinwheel extract, which showed that phenols, flavonoids, tannis, and alkaloids were present but that terpenoids and saponins were not. The presence of alkaloids, flavonoids and phenolics phytonutrients in pinwheel flower extract is thought to be responsible for the bioreduction process. To study that FTIR investigation was carried out to see the involvement of related functional group from extract in AgNP synthesis.

Table 1 Qualitative Screening Results of Pinwheel Flower Extract

Alkaloids	Tannis	Flavonoids	Phenols	Terpenoids	Saponins
√	√	√	√	×	×

4.2 UV-Visible Spectroscopy:

It is commonly known that the activation of surface Plasmon vibration in silver nanoparticles causes them to appear yellowish brown in aqueous solution [18]. The colour of AgNPs produced from flower extract is shown in Fig. 2. UV-visible spectroscopy can be used to analyse the size and form of the nanoparticles in aqueous suspension. The UV-Vis absorption spectra of the biosynthesized AgNPs with 2, 3, 4, and 24 hours reaction time is displayed in Figure 3.

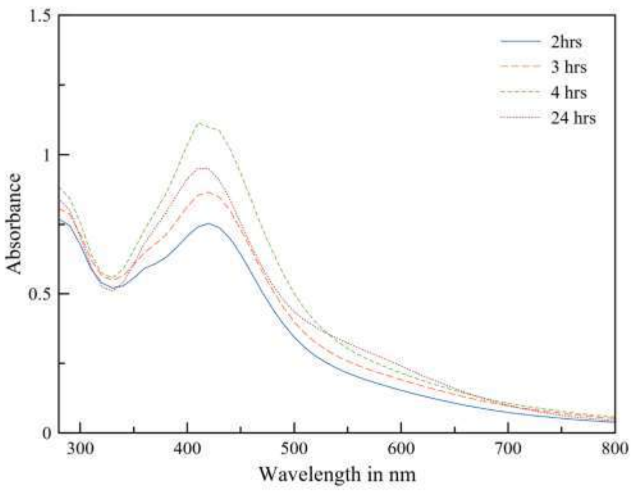

Figure 3 : UV-Visible spectrum of biosynthesized AgNPs with reaction duration of 2, 3, 4 and 24 hours

It reveals that the generation of AgNPs started within 2 hours. The maximum absorption peak of synthesized silver nanoparticles is achieved at 410 nm which confirms the formation of AgNPs in the size range of 60-80nm, based on published literatures [18]. UV-visible spectroscopy was used to verify the stability of the synthesised silver nanoparticles for a full day (up to 24 hours). This method confirmed a consistent SPR peak at 410 nm, although with a lower absorbance.

4.3 FTIR Analysis:

FTIR analysis was used to evaluate the data related to the chemical alteration of the functional group involved in bio reduction. Figure 4 displays the FTIR absorption spectra of the pinwheel flower extract and the biosynthesized AgNPs. The Pinwheel flower extract shows the strongest peak at 3340cm-1, 1637 cm-1 and 1043 cm-1 attributed to OH group, olefinic band and primary and secondary alcohol functionalities respectively. In case of AgNP synthesized using flower extract similar pattern of FTIR spectrum was achieved. However, it was discovered that the positioning and peak area of corresponding peaks slightly changed. FTIR Peaks at 3340, 1637, and 1043 corresponding OH, C=C, and C-O observed in flower extract were found to get narrowed and shifted to higher frequency regions. It confirms the involvement of OH and C-O groups from flower extract in the reduction of ionic silver to nanosilver. This further supports the hypothesis that the reduction and stabilisation of synthesised silver nanoparticles are caused by phytonutrients with OH and C-O functional groups in their structures, such as flavonoids, alkaloids, and phenolic chemicals.

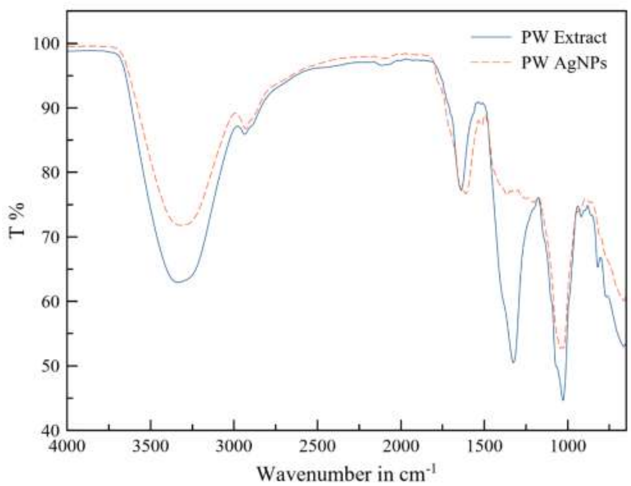

Figure 4: FTIR spectra between Tabernaemontana divaricta flower (pinwheel flower) extract and synthesized silver nanoparticles

AgNP generation occurs in high quantities and is smaller than 100 nm, as shown by the scanning electron micrograph (Fig. 5) of silver nanoparticles made using pinwheel flower extract. The particle size of the synthesized silver nanoparticles fall between 30 and 120 nm, with the largest particles measuring between 50 – 90nm, almost matching the values reported through UV-visible spectroscopy investigation.

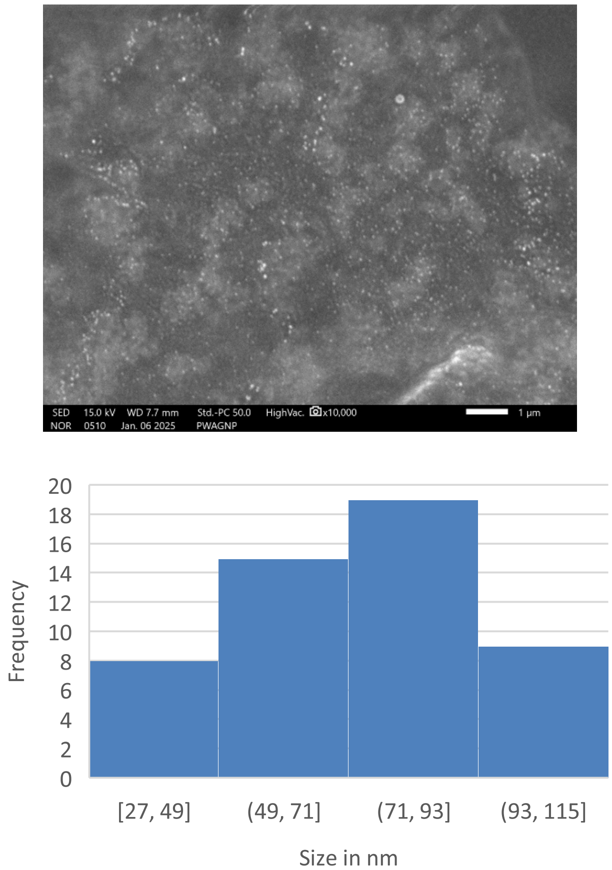

Figure 5: Scanning electron microscope image and size distribution histogram of synthesized silver nanoparticles

In comparison to their salt counterparts, silver nanoparticles have strong antibacterial properties due to their large surface area, which enables improved contact with microorganisms. Using the AATCC 100 standard test method, the antibacterial activity of textiles deposited with AgNPs was evaluated against Staphylococcus aureus and Klebsiella pneumoniae. AgNP-deposited fabric demonstrated outstanding antibacterial activity against both Gram-positive (Staphylococcus aureus) and Gram-negative (Klebsiella pneumoniae) bacteria; that is after 24 hours, the antibacterial rate increased to 99.80% against Klebsiella pneumoniae and 99.71% against Staphylococcus aureus. The cause might be that the small size of AgNP particles causes them to firmly adhere to the surface of bacterial cells, disrupting the cell membrane and ultimately killing the bacteria [19]. These biosynthesized AgNP-deposited samples then assessed for wash durability in terms of change of its related antimicrobial properties after 10 numbers of soap washes. After ten washes, antimicrobial properties of same fabric is 99.29 % for gram negative and for gram-positive, it is 98.90%. Excellent antibacterial activity and wash durability in cotton fabric are the results of the overall homogeneous deposition of biosynthesised AgNPs on cotton fabric, making them appropriate for commercial applications.

5. Conclusion

Using pinwheel flower extract as the reducing agent, a straightforward bioreduction synthesis technique for AgNP synthesis has been reported. These synthesized nanoparticles were examined using SEM, FTIR, and UV-visible spectroscopy. The particle size of AgNPs was theoretically obtained as 60 – 80nm by Uv-visible spectroscopy and SEM studies. These biosynthesized AgNPS were then applied over cotton fabric using a simple pad-dry-cure process and antibacterial activity, and wash durability were evaluated. AgNP deposited fabric showed excellent antimicrobial activity and wash durability against Klepsillaknumoniae and Staphylococcus aureus. This work can be further extended to the practical application of biosynthesized AgNPs in the pharmaceutical industry and wastewater treatment.

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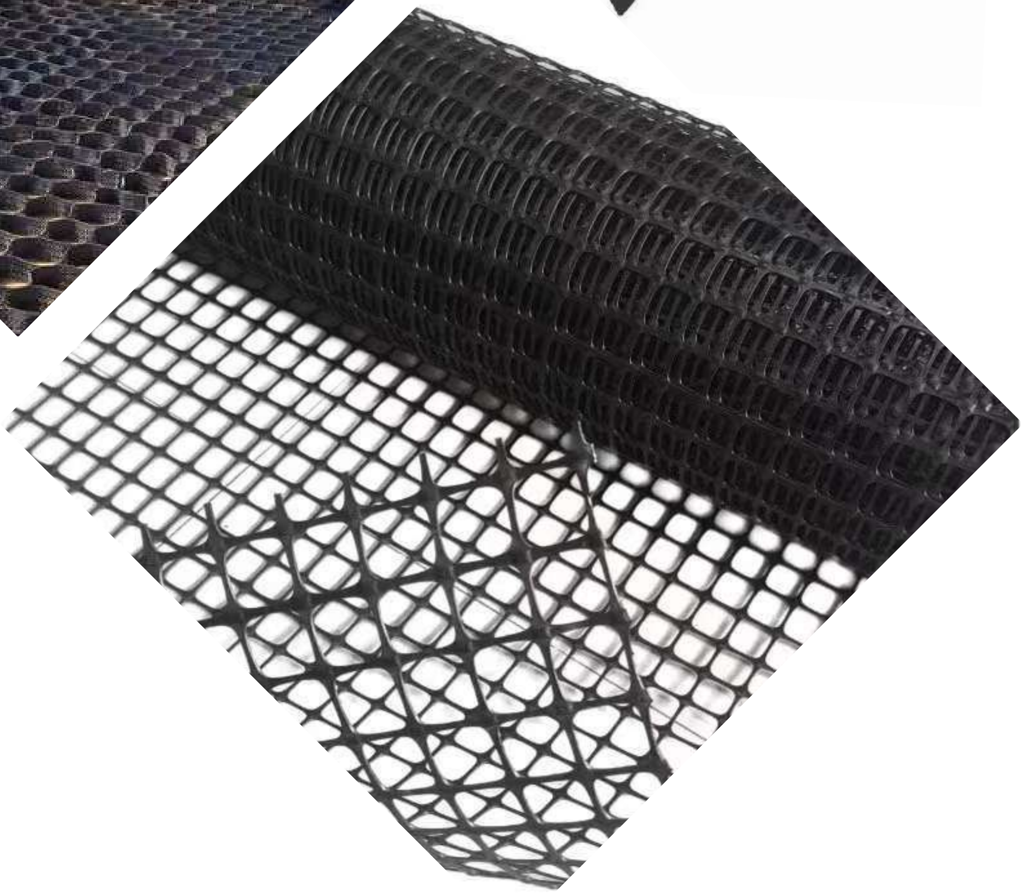
References

1. Khan I., Saeed K., Khan I., Nanoparticles: Properties, applications and toxicities,Arab. J. Chem. 2019, 12, 908-931, https://doi.org/10.1016/j.arabjc.2017.05.011
2. JoudehN., Linke D., Nanoparticle classification, physicochemical properties, characterization, and applications: a comprehensive review for biologists, J Nanobiotechnol. 2022,20, 262 https://doi.org/10.1186/s12951-022-01477-8
3. Wu Q., MiaoW., Zhang Y., Gao H. and Hui D, Mechanical properties of nanomaterials: A review, Nanotechnology Reviews. 2020, 9, 259-273. https://doi.org/10.1515/ntrev-2020-0021
4. Patra, J.K., Das, G., Fraceto, L.F., Campos E.V. R., Rodriguez-Torres M.P., Acosta-Torres L. S. Diaz-Torres L. A., Grillo R., Swamy M.K., Sharma S., Habtemarium S. and Shin H., Nano based drug delivery systems: recent developments and future prospects,J Nanobiotechnol2018. 16, 71.https://doi.org/10.1186/s12951-018-0392-8
5. Lee SH, Jun B-H. Silver Nanoparticles: Synthesis and Application for Nanomedicine. International Journal of Molecular Sciences. 2019; 20(4):865. https://doi.org/10.3390/ijms20040865
6. Mulenos M.R, Lujan H, Pitts LR, Sayes CM. Silver Nanoparticles Agglomerate Intracellularly Depending on the Stabilizing Agent: Implications for Nanomedicine Efficacy. Nanomaterials. 2020; 10(10):1953. https://doi.org/10.3390/nano10101953

7. Chaudhery S. P., Hussain M., Chapter 1 - Functionalization of nanomaterials for industrial applications: recent and future perspectives, Editor(s): Chaudhery Mustansar Hussain, In Micro and Nano Technologies, Handbook of Functionalized Nanomaterials for Industrial Applications, Elsevier, 2020, Pages 3-14, ISBN 9780128167878, https://doi.org/10.1016/B978-0-12-816787-8.00001-6.
8. Subhan M. A, Choudhury K. P, Neogi N. Advances with Molecular Nanomaterials in Industrial Manufacturing Applications. Nanomanufacturing. 2021; 1(2):75-97
https://doi.org/10.3390/nanomanufacturing1020008
9. Dahl J. A.,Maddux B. L. S., and Hutchison J. E., Chemical Reviews2007107 (6), 2228-2269 DOI: 10.1021/cr050943k
10. Khan A., Rashid A., Younas R., Chong R., 'A chemical reduction approach to the synthesis of copper nanoparticles', Int Nano Lett (2016) 6:21–26
11. Kaur R. Giordano C. , Gradzielski M ,Mehta S. K.Synthesis of Highly Stable, Water-Dispersible Copper Nanoparticles as Catalysts for Nitrobenzene Reduction, Chemistry J, 2014, 9, 189-198.
12. Caroling G., Vinodhini E., Ranjitham A. M. and ShanthiP..Biosynthesis of Copper Nanoparticles Using Aqueous Phyllanthus Embilica (Gooseberry) Extract- Characterisation and Study of Antimicrobial Effects, Int. J. Nano. Chem, 2015. 1, No. 2, 53-63.
13. Sahni G. PanwarA.Kaur B., Controlled green synthesis of silver nanoparticles by Allium cepa and Musa acuminata with strong antimicrobial activity, Int Nano Lett , 2015, 5, 93-100 DOI 10.1007/s40089-015-0142-y
14. Sukumaran S., KirubaS.,Mahesh M, Nisha S.R., Paul Z. M., Ben C.P., Jeeva S., Phytochemical constituents and antibacterial efficacy of the flowers of Peltophorumpterocarpum (DC.) Baker ex Heyne, Asian Pac.J. Trop. Med., 2011,4, 735-738 https://doi.org/10.1016/S1995-7645(11)60183-1.
15. Esfanddarani H.M., Kajani A. A., Bordbar A., IET Nanobiotechnol, 2018,12(4):412-416 doi: 10.1049/iet-nbt.2017.0166
16. Vankar P.S and Shukla D.,Biosynthesis of silver nanoparticles using lemon leaves extract and its application for antimicrobial finish on fabric, Appl Nanosci 2012, 2, 163-168.
17. Das B.K., Al-Amin M.M., Russel S.M., Kabir S., Bhattacharjee R., Hannan J.M.. Phytochemical Screening and Evaluation of Analgesic Activity of Oroxylum indicum. Indian J Pharm Sci. 2014, 76(6), 571.
18. Agnihotri S., Mukherji S. and Mukherji S., Size-controlled silver nanoparticles synthesized over the range 5–100 nm using the same protocol and their antibacterial efficacy, RSC Adv., 2014, 4, 3974-3983
19. More P.R.,, Pandit S., Filippis A.D., Franci G., Mijakovic I., Galdiero M. Silver Nanoparticles: Bactericidal and Mechanistic Approach against Drug Resistant Pathogens. Microorganisms. 2023; 11(2):369. https://doi.org/10.3390/microorganisms11020369 of the ageing characteristics of VG-30, RAP and HiMA using FTIR. Construction and Building Materials, 366, p.130185.



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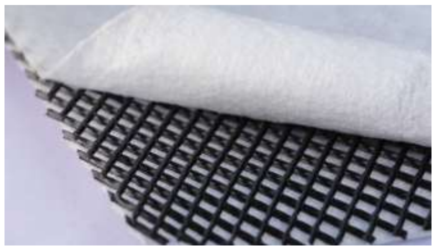

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