Old title: An Experimental study on Developing an Antimicrobial and Insect Repellent Fabric for Preservation of Textiles

Revised title: Textile Preservation: Intervention of Nanotechnology in Traditional Practices

Synopsis of Proposed Thesis

by

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Registration Number FOF/173 **Dated: September 16, 2016**

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Endorsement from the Supervisor

Ms. Ankita Shroff has researched on “Textile Preservation: Intervention of Nanotechnology in Traditional Practices” with registration number FOF/173, (Dated: September 16th, 2016). She conducted extensive work which have been substantiated its originality. She has presented her progress of work in seminars well attended by external committee, teachers, and students of the department. During the course, she has received University Doctoral Scholarship from November 2018 to November 2020 by the Maharaja Sayajirao University of Baroda. She has also bagged two international scholarships: The Shastri Indo-Canadian Scholarship for the period of six months in 2019 and the MITACS Accelerate Fellowship from 2021-2022 for one year and three months at the University of Alberta, Canada.

At the University of Alberta, Ankita has worked on a part of her research test application and characterization. Along with that she has worked full time on various research projects as a project lead and as a project member for developing various textile finishes. She has also presented her research progress of work in seminars well attended by teachers and students of the Department at the University of Alberta.

While she was in Canada, she had presented a paper at the Institute of Textile Science on “Cinnamon oil loaded chitosan nanoparticle finish for preserving museum textiles” on March 8, 2021. She was also invited as a conference speaker to deliver an oral presentation on “Developing a Preservation-Promoting Fabric for Museum Textiles” at the 8th edition of the International Conference on Intelligent Textiles and Mass Customization- ITMC 2022, held at the city of Montreal (Canada), from September 19 to 21, 2022. An individual abstract has been published in the conference proceedings for each of the aforementioned papers that were presented at the conferences. A book chapter on Nanotechnology-Based Interventions in Museum Textiles has been published in December 2022 in the Handbook of Museum Textiles- Volume 2: Scientific and Technological Research. Along with that two more papers are prepared for publications in due course of time.

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1. Introduction

Textiles play a rich part in the lives and traditions of people of all cultures. A Museum collection generally interprets important objects that document the past and present human life, cultural values, and their artistic creations. Traditional textiles were usually made of natural fibers which makes them difficult to preserve even under the best conditions. They are easily degraded by a combination of various biological, chemical, and physical factors such as such as inappropriate lighting, improper temperature and relative humidity levels, presence of dust, mishandling, and improper restoration methods. [1]. This is especially prevalent for cellulose-based textiles, such as cotton, linen, jute, and protein-based fibers like silk and wool, as these materials provide a favourable environment including source of food for microorganisms, insects like silverfish, cloth moths, bugs, carpet beetles, ants, and other living organisms [1, 2]. The degradation generally takes place at the surface of the textile [3]. When textiles are exposed to these variables, they tend to develop discoloration, brittleness, corrosion of metallic components, a sweet or musty odour, small irregular shaped holes, and eventually accelerate ageing by completely degrading them [1].

Damages caused by these living organisms to textiles, are irreversible. These heritage textiles should be protected from these damages by either controlling the ambient conditions of temperature and humidity or treating the fabrics with biocidal and insect-repellent products. There are several natural and synthetic compounds used as biocide and insect repellent by conservators and curators in museums [4]. It is understood that any treatment applied to museum textiles should be reversible and not cause any further weakening of the fibers.

One of the oldest practices for the preservation of textiles in India is based on the use of herbs and spices like clove, cinnamon, carom seeds, camphor, dry leaves of *Azadirachta indica* commonly known as Neem, tobacco leaves, tulsi, and eucalyptus [4, 5, 6]. The dry herbs and spices are contained in small textile bags placed on the shelves or in the boxes where the textiles are stored. They possess biocidal and insect repellent properties that can be associated with the presence of active compounds such as eugenol in clove, monoterpenes in camphor, nicotinic acid in tobacco leaves, phenolic compounds in lavender oil, and carvacrol (a phenolic monoterpenoid) in oregano. It is thought that many plant volatiles are repellent to insects because of high toxicity in the vapour phase. For instance, essential oils from cedar wood, peppermint, citronellal, ocimum basilium, lemongrass, and nutmeg have demonstrated their efficiency against woolen moths [7]. Clove buds, oregano and thyme leaves, cinnamon sticks, and cumin seeds, which have flavored food since ancient times, have demonstrated significant antibacterial and antifungal properties [8]. Improved performance against specific bacteria has been observed with combinations of spices.

However, a significant drawback of placing a small bag of the mixed herbs or spices on a shelf is that it does not create a strong repellent environment over a large circumference area [4, 6]. In addition, the active compounds contained in herbs and spices are generally sensitive to light and thus cannot be applied directly on a fabric or a surface [9].

Due to a high demand of great care, preservation, and conservation of these unique textiles, it is essential to use appropriate techniques to protect, preserve, and conserve them for our future generations. To overcome these challenges, nano encapsulation of essential oils could be the way forward to provide the biocidal and insect repellent function to the textiles [11].

The essential oils forming the core of the capsules diffuse through the capsule polymer shell, allowing a controlled release of the active compounds and providing a long-lasting protection to the textiles against bacteria, fungi, and insects. The shell also protects the active compound from oxidation and UV degradation. The application of these essential oil-containing capsules is done on a separate fabric that will be used to wrap the heritage textiles when in storage, as a lining for flat storage, and as padding on hangers and rollers, thus avoiding direct application to the ancient textiles. It can also be used as a backing or covering material for displays.

Such a holistic perspective is the key to slowing down the degradation processes and limiting further aging of museum textiles while preserving as much as possible their unique characteristics for now and future generations.

1.1 Purpose of the study

Museum collections consist of textiles and costumes that are irreplaceable records of our past. It is critical to preserve them to maintain the history of humankind. However, they demand great care, preservation, and conservation. Textiles are easily degraded by environ- mental conditions involving a combination of various biological, chemical, and physical factors [1]. Damage to ancient textiles can also be caused by mishandling. The degradation generally takes place at the surface of the textile [2]. In addition, being organic in nature, textiles are likely to attract microorganisms, insects, and other living organisms [3]. This is especially prevalent for cellulose-based textiles, such as cotton, linen, jute, and protein-based fibers like silk and wool, as these materials provide a favorable environment for living organisms, including a source of food in some instances. Therefore, there is a need to preserve the ancient textiles against microbes and insects without any direct application on them, and without any use of harmful chemicals or gases which intern will lead to increase in deterioration.

The fabric under the study is developed using a nano structured finish which enhances the durability of the finish that will help protect against the microbes and insects. The improved durability provided by the finish on the textile is associated with the large effective surface area of nano particles [6, 15]. These nano particles are developed using essential oils as active compounds which are dispersed in a chitosan polymer matrix and a binder to apply on a fabric substrate.

Due to the control release mechanism of the nano particles, the fabric leaches out the active compounds and thus repel microbes and insects. Hence, proving the best means and ways for a greater durability of the antimicrobial and insect repellent finishes. This developed preservative fabric will be used to cover or wrap and store the textiles into it. It can also be used as a backing or a lining fabric to the drawers, cupboards, boxes. The fabric can be used for padding the hangers and rollers for storage purposes. As it will be used for wrapping the textiles, it will also cover and preserve the stored textiles against dirt and dust, thus avoiding direct application to the ancient textiles.

The preservative fabric developed under this study would help developing a scientific environment for our heritage textiles to increase its lifespan, thus preserving them for our future generations. The research would also sensitize the current and future generations about the traditional indigenous practices of preserving the textiles. In many cultures, textiles play various important roles. Historically, some were reserved for ceremonial purposes while others were reserved for, and worn only by specific classes of people. Special textiles hold sentimental value related to the stories and storytellers all across the world, several of which are quilts and heirloom textiles. These memories can be cherished along with the items, and preserving them for the memories they hold and the hard lives and fun times they represent of those that have passed on may be important for the generations and generations to follow. The fabric developed under the study can also be used by the individuals at home to preserve their heirlooms and for some their personal collections.

1.2 Objectives

1. To study and understand the preservative practices adopted by textile museums and by individuals at home.
2. To isolate and identify the microorganisms present on the deteriorated cellulosic and protein fabrics.
3. To identify the essential oils and develop nanoparticles using the same.
4. To study and compare the properties of nanoparticles in terms of its particle size, encapsulated efficiency, and retention property.
5. To determine the minimum inhibitory concentration of the developed nanoparticles and to compare its efficacy using individual and combination of nanoparticles against the selected microbial strains.
6. Application of the optimized essential nanoparticles on the substrate and to test the microbial and insect repellency.

1.3 Scope of the Study

The study offers very interesting perspectives to improve and overcome the draw- backs of the traditional methods of preservation and conservation used for heritage artifacts in museums without altering their original properties of the ancient textiles. The preservative fabric gives a scientific environment for our heritage textiles to increase its lifespan. Another interesting advantage of the developed finish is that use of toxic and non-environmentally friendly chemicals or gases for preservation can be avoided. The efficacy of the fabric covers a large circumference and for a longer duration due to the control and release mechanism of the nanoparticles involved. Hence, proving the best means and ways for a greater durability of the antimicrobial and insect repellent finishes. This intern will aid in preserving textiles for longer time and for our future generations. The research would also sensitize the current and future generations about the traditional indigenous practices of preserving the textiles.

2. Review of Literature

This chapter discusses the relevant published and unpublished studies that are required to comprehend the theoretical and research perspective of the preservative practises adopted for textiles, the science and technical know-how underlying the traditional natural preservatives used, the techniques required to develop the nanoparticles, and the steps in characterising the developed finished before and after employed on the substrate. The data was collected from various sources like libraries, museums, journals, books, blogs, and websites. The factors that contributed to the different aspects of the study were as follows:

2.1 Heritage textiles

2.2 Textile degradation- Types and their effects

2.3 Traditional solutions for combating bacterial and insect infestations

2.4 Current approaches towards textile preservation and conservation

2.5 Application of natural agents for the antimicrobial property

2.6 Essential oils: Chemical composition, antimicrobial and insect repellent mode of action and its limitations and challenges

2.7 Nanotechnology

2.8 Nanotechnology for developing antimicrobial carriers

2.9 Chitosan based nanocarriers

3. Methodology

This chapter deals with the methods, procedure and standards required to develop a finish focused on anti-microbial and insect repellent finish to preserve the textiles. An extensive review and a survey were conducted at several textile museums and with individuals who are textile enthusiastic with their personal textile collection to understand the preservative practices used for the textiles. Later, an experimental approach was taken to understand the microflora environment of a preserved cellulosic and proteinic natured textile, isolation and identification of the microbes on a preserved cotton, wool, and silk fabric was performed. Finally, a finish was developed using different types of a two-step process, consisting of the microemulsion and ionic gelation method and emulsion and ionic gelation method to develop nano particles which were coated on a fabric with the help of a binder. The characterization and surface analysis of the nanoparticles and the coated fabric was conducted to test their structure, properties and its application for preserving textiles against microbes and insects.

Research Design

Phase I

Studying the preservation practices followed at Museums and by individuals at home

Content study of herbs and spices employed for textile preservation

Identifying the microorganisms present on the deteriorated cellulosic and protein textiles

Phase II

Cotton fabric Polyester fabric

Preliminary Data

1. Fabric Count
2. Fabric GSM

Preparation of essential oil nanoparticles

Wall material:

Chitosan

Core material:

1. Neem oil
2. Clove oil
3. Camphor oil
4. Carom oil

Parameters:

- Chitosan %
- Polymer:Oil
- Surfactant %
- Acetic acid %
- Crosslinking agent%
- Method of Preparation

Analyzing properties:

1. Determining the calibration curve of the essential oil.
2. Assessing the Size of the nanoparticle (Malvern Zetasizer)
3. Determining the Encapsulation efficiency
4. Determining the Loading capacity
5. Determining the Minimum Inhibitory Concentration (MIC) of the nanoparticles against the selected microbial strains

Phase III

Analyzing and comparing of functional compounds for the antimicrobial and insect repellent property and their efficacy during their encapsulation on cotton and polyester fabric

1. Surface analysis of the nanoparticle using SEM
2. EDX analysis of the finished fabrics
3. Determining the physicochemical stability of the nanoparticles over time and storage
4. Assessment of Antibacterial activity of the finished cotton and polyester fabric by Parallel Streak Method (AATCC 147)
5. Determination of Antifungal activity: Mildew and Rot resistance (AATCC 30)
6. Insect repellent test (ISO 3998: 1997)

Methods and procedure followed in order to elicit the necessary data for objectives are as follows:

3.1 Documenting the preservative practices adopted by textile museums and by individuals at home:

The researcher had visited various museums to collect secondary source data from the Calico Museum in Ahmedabad, Raja Dinkar Kelkar Museum in Pune, National Museum in New Delhi, Crafts Museum in New Delhi, and the Textile Art Museum at the Department of Clothing and Textiles, The Maharaja Sayajirao University of Baroda, Vadodara, and Baroda Museum and Picture Gallery, Vadodara. To conduct the interviews with the textile collectors, conservators, and museum curators, an open-ended questionnaire was created. Additionally, details on the textiles' preservation and conservation methods were acquired from primary data sources.

3.2 Isolating and identifying the microorganisms present on the preserved cellulosic and protein fabrics undergone deterioration:

Selected fabrics included over 60 years old cotton and silk that had been preserved by being wrapped in mulmul in the presence of naphthalene balls. These fabrics had degraded and were shredded when pulled apart. Wool fabric that had been stored in a department of clothing and textiles storage area for more than 30 years in the presence of naphthalene balls and had holes in it from moth infestation was also chosen for the investigation to isolate and identify the bacteria and fungi that had grown on these materials. Three samples of each fabric measuring 10X10 cm that were taken from the three separate locations were used for the isolation of the bacterial and fungal colonies, which was done using a saline solution and suspended on nutrient agar for growth. The developed colonies were subsequently sub-cultured on several agar plates and identified using their morphological characteristics. The entire procedure was carried at the Department of Microbiology, The Maharaja Sayajirao University of Baroda.

3.3 Identifying and developing nanoparticles using essential oils:

The selection of the essential oils was made in accordance with the review and the preliminary information gathered from the interviews conducted with museum curators and private textile collectors. A two-step procedure of emulsification and ionic gelation, as well as the microemulsion and ionic gelation methods, were used to synthesize the chosen essential oil nanoparticles with chitosan coated polymer. At the pharmacy faculty of The M S University of Baroda, all the parameters for creating the nanoparticles were developed and optimized.

3.4 Evaluation of the properties of nanoparticles:

The screening of the parameters of the various developed essential oil nanoparticles were evaluated for its entrapment efficiency and oil loading capacity by analyzing them using UV–Vis spectrophotometry at their particular wavelengths. The size and the polydispersity index (PDI) of the developed nanoparticles was identified using Dynamic Light Scattering (DLS) is a system on a Malvern Zetasizer. To study the surface morphology, the nanoparticles were centrifuged and the pallets were lyophilized to send for the scanning electron microscope (SEM) analysis at IIT, Delhi. In order to confirm the formation of the nanoparticles and its absorbency on the coated fabric, energy-dispersive X-ray spectroscopy (EDX) analysis was also performed at the NanoFab laboratory of the University of Alberta. Lastly, the physicochemical stability of the nanoparticles over time and storage condition at room temperature (25°C± 2), 65 ± 2% RH was also carried out for two months to determine the rate of essential oil releasing from the nanoparticles.

3.5 Determining the minimum inhibitory concentration of the developed nanoparticles and comparing its efficacy using individual and combination of nanoparticles against the selected microbial strains:

The two-fold dilution method is considered a gold standard technique of antimicrobial susceptibility testing that is characterized by its accuracy in determination of the minimum inhibitory concentrations (MICs), and the ability to extend the antimicrobial concentration as far as required. The MICs of the developed nanoparticles were performed individually and in combination against the selected gram-positive and gram-negative bacterial strains.

3.6 Application of the optimized essential nanoparticles on the substrate and testing the microbial and insect repellency:

The best performing dilution nanoparticles were then applied on the selected substrate i.e. cotton and polyester fabric using spraying and pad dry cure method. The choice of a polyester fabric was made because, due to its synthetic character, it naturally repels insects and microbes to a greater extent than cotton does. The additional finish applied to the polyester fabric would increase its resistance to these biological degrading agents. The nanoparticle coated fabric specimens were evaluated for its antibacterial and antifungal activity following standard AATCC 147 and AATCC 30. For the insect repellency test, ISO 3998: 1997 test was followed to test against cigarette beetle larvae. The insect repellency test against cloth moth and/or silver fish has been planned in the due course of time depending upon their procurement.

4. Results and Interpretations

The research was aimed to develop a finish coated fabric focusing on anti-microbial and insect repellent property that can be used to preserve the heritage textiles and thereby slowing down the degradation processes and limiting their further aging.

Phase I of the research covers the following points:

4.1 Documenting the preservative practices adopted by textile museums and by individuals at home:

A common practice for preservation of textiles followed at all the museums and by the textile collector at homes was the use of a small bag made of mulmul fabric stuffed with natural herb and spices like clove, camphor, carom seeds, and cinnamon sticks where the textiles are stored. In addition to this, the textiles were placed on the shelves and drawers, which had a layer of either dried neem leaves or tobacco leaves sandwiched between mulmul cloth. The use of naphthalene balls was also rather typical. Besides, fumigation was yearly done on textiles that were infested by insects at the museums.

4.2 Isolating and identifying the microorganisms from the preserved cellulosic and protein fabrics undergone deterioration:

The bacterial colonies were observed more on cotton fabric as compared to silk and wool fabric. Gram-positive bacteria's like *Bacillus cereus*, *Micrococcus* and *Staphylococcus aureus* was observed to be high in number as compared to the gram-negative bacteria like *Pseudomonas*. Fungal colonies observed on all the three fabric were majorly *Aspergillus Niger,* and *Aspergillus Fumigatus*.

Phase II covers the following points:

4.3 Identifying and developing optimized nanoparticles using essential oils:

The selected essential oils under the study were cinnamon oil, clove oil, camphor oil, carom seed oil and neem oil. Microemulsion and ionic gelation method was used to develop neem oil. Whereas, for the other oils emulsion and ionic gelation method was used. Clove oil was developed using both the techniques, but emulsion and ionic gelation method gave better results. The parameters that impacted the formation of the nanoparticles were as follows:

- Impact of stirring rate (RPM) on the average size and entrapment of the essential oil chitosan nanoparticles: For both procedures, various stirring speeds at various stirring times were employed. Particle size diameter was significantly influenced by homogenization speed. It was discovered that speeding up homogenization greatly reduced the size of the nanoparticles. Low RPM caused the nanoparticles to aggregate and increase in size. Additionally, it was found that rapid increases in homogenization speed were unfavourable because they caused the medium to absorb a lot of energy, which in turn caused the essential oils to evaporate, particle aggregation or particle bursting in some cases, and particle enlargement rather than particle size reduction.
- Effect of chitosan concentration on the amount of entrapped essential oil: Low chitosan concentration was associated with insufficient molecule availability, which reduced entrapment. Less oil entrapment caused phase separation, which resulted in the observation of creaming. Whereas, high chitosan concentration led to increase in viscosity and turbidity of the solution leading to less entrapment due to poor penetration of oil.
- Sodium tripolyphosphate (TPP) concentration on the average size of the nanoparticles: TPP was used as a negatively-charged cross-linker that was added to the nano emulsion to interconnect the positively charged chitosan polymer chains. Different TPP concentration was employed (1, 2, and 3%). Less TPP concentration caused inadequate cross linking, leading to soft wall of the particle (chitosan) whereas high TPP led lysis of the nanoparticles
- Impact of surfactant concentration on the particle size and entrapment of the nanoparticles: For all the essential oils, two different surfactants, Tween 80 and Poloxamer 188, were used at various concentrations (0.5, 0.75, 1, and 2%). Low surfactant concentration resulted in

insufficient surface tension reduction, which caused the particles to aggregate, and high surfactant concentration resulted in foaming and increased viscosity, which increased particle size and impairing nanoparticle formation, which had an impact on entrapment.

4.4 Characterization of the developed nanoparticle formulation:

- Using the dynamic light scattering (DLS) approach, the hydrodynamic size of the nanoparticles was investigated on Malvern Zetasizer. The average diameter of the nanoparticles comprised of clove essential oil was 294 ± 12 nm, those made up of neem oil were 189 ± 14nm, and those made up of cinnamon essential oil were 226 nm ± 8 nm. While the measurements for camphor oil were 218 ± 16 nm and 349 ± 18 nm, respectively, for carrom oil. The Polydispersity index of the developed nanoparticles was 0.2 ±3.
- Neem chitosan nanoparticles had a 78% core entrapment efficiency, whereas cinnamon and carom essential oils had entrapment efficiencies of 74% and 71%, respectively. A 52% entrapment efficiency was seen in the clove chitosan nanoparticles, in contrast. The lowest amount of entrapment was 24.31% for camphor oil. This can be due to the fact that camphor oil, which has the lowest density (0.88 g/cm3) compared to other essential oils, can be highly volatile, which may have made it less stable during the preparation process and contributed to the lower percentage of entrapment. Camphor essential oil was therefore excluded at this step.
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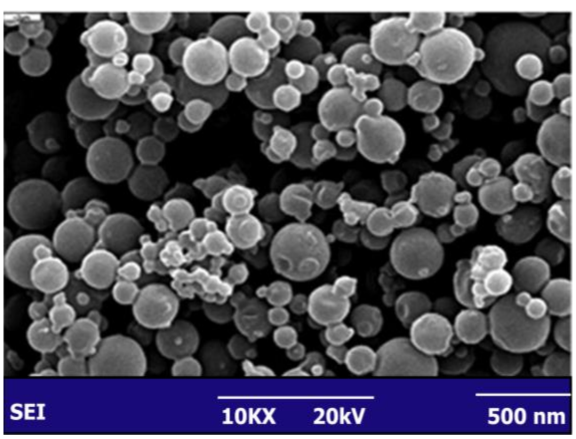

Fig 1: SEM image of Neem essential oil chitosan nanoparticles

- The surface analysis of the optimized nanoparticles with the higher entrapment efficiency was then lyophilized for performing SEM. The SEM images showed that the nanoparticles formed were spherical in structure with absence of cracks and showed a formation of continuous wall layer. An example of neem chitosan nanoparticles is shown in the figure 1.

4.5 Determining the minimum inhibitory concentration of the developed nanoparticles and comparing its efficacy using individual and combination of nanoparticles against the selected microbial strains:

The MIC results with two-fold dilution system showed average results of 1:8 dilution for *Bacillus cereus, Staphylococcus aureus, Pseudomonas, and E. coli.* The combination of cinnamon and clove nanoparticles showed the highest minimum inhibition concentration when compared to neem and clove nanoparticles.

4.6 Application of the optimized essential nanoparticles on the substrate and testing the microbial and insect repellency:

The optimized nano particles individual and in combination were diluted in distilled water at the ratios that displayed the best MIC results along with 10% citric acid binder. The application was done by dipping both the selected substrate cotton and polyester fabric in the finish followed by passing it through a padding mangle with 2 dip and 1 nip running at 15m/min, pressure of 15 kgf/cm2, followed by curing at 40C for 5 minutes.

Fabric samples of 2X2 cm were cut from random places of both the treated fabric to perform antibacterial and antifungal test along with an untreated (controlled) fabric and also with a blank chitosan nanoparticle to see the effect of just chitosan on the antimicrobial behavior and to compare that with the essential oil loaded nanoparticles. The tests were performed in triplicates. Antibacterial test was performed against gram-positive and gram-negative bacterial strains. The results for cotton fabric indicated that gram positive bacteria were more resistant to it than gram negative bacteria. Additionally, it was shown that the combination of nanoparticles performed better in repelling bacteria than the individual nanoparticles coated on the fabric. A test for antifungal effectiveness was run on Aspergillus fumigatus. The results for cotton fabric showed no repellency zone, but at the same time, no fungal growth was seen on the fabric's surface. For antibacterial and antifungal test for the treated polyester fabric showed no resistance. Fungal growth was also observed on the surface of the treated polyester fabric.

In contrast to polyester fabric, where no presence of elements was observed except for carbon and oxygen, the EDX analysis of the essential oil chitosan nanoparticles confirmed the presence of carbon and oxygen with high intensity peaks and low intensity peaks of other elements like sodium, calcium, phosphorus, and silicon that are obtained from chitosan on cotton fabric.

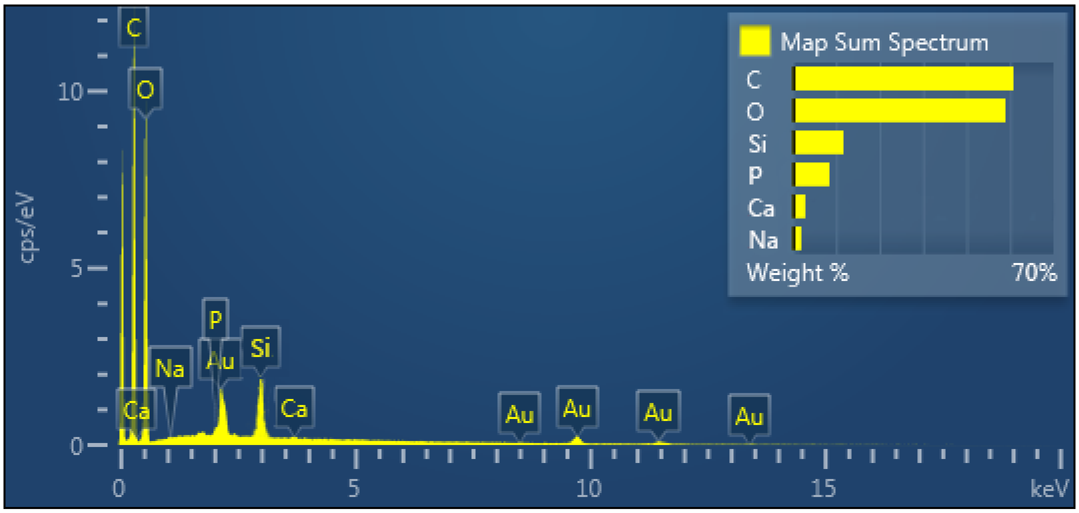

Fig 2: EDX image of clove essential oil chitosan nanoparticles treated cotton fabric conforming the presence of minerals like calcium, sodium, phosphorus and silicon from the chitosan.

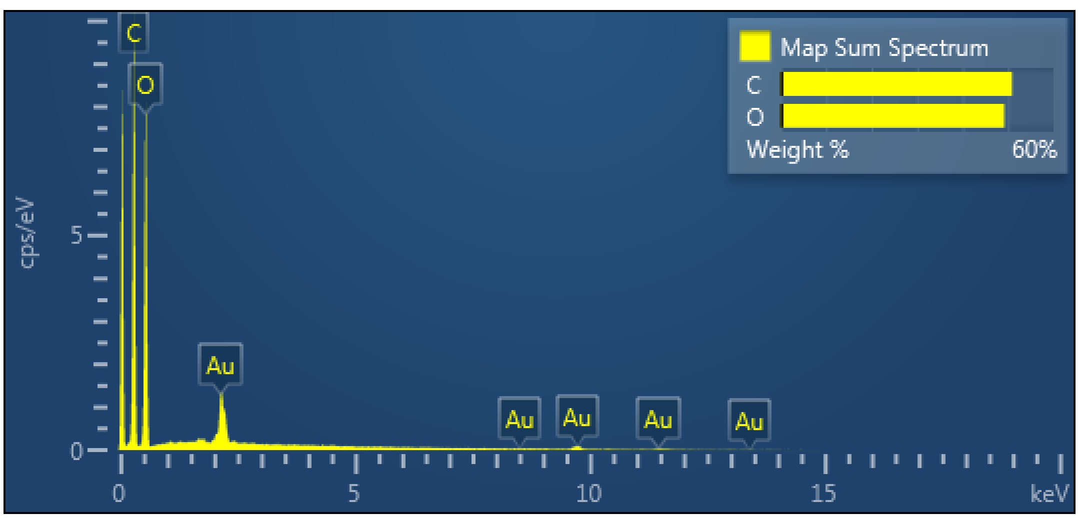

Fig 3: EDX image of clove essential oil chitosan nanoparticles treated polyester fabric showing no traces of minerals

The lack of impact of the polyester fabric could be attributed to the hydrophobic property of the fabric leading to poor ability to absorb the finish, which was supported by the EDX test. As a result, the polyester fabric was discarded, and the further tests were conducted only on the cotton fabric.

The *in-vitro* study was done on the nanoparticles that were coated on the cotton fabric substrate at the room temperature in a closed petri dish and in an uncovered petri dish exposed to environment. Keeping the end use of the fabric in mind which will be used in an open environment and in an enclosed environment in a drawer or shelves at a room temperature, the parameters were set accordingly. For analysis, the covered and uncovered samples were soaked in the suitable solvent and the absorbance was calculated using UV spectrophotometer and the percent oil content after one month and two months was compared to zero time (after nanoparticle preparation). The results showed that the fabrics that were kept covered in a petri dish showed better stability as compared to the ones kept uncovered and exposed to environment. Neem nanoparticles showed the best results in terms of % change in the content with 2.7% change after two months in covered condition and 12.8% change after two months in uncovered condition. Clove nanoparticles showed maximum % change in the content at 22% when kept uncovered.

The treated and untreated cotton fabrics were tested for their ability to repel cigarette beetle larvae, which are frequent insect identified in museums after silverfish and cloth moths. The test was conducted and evaluated in accordance with ISO 3998: 1997. Weight loss or any surface flaws like yarn breaking or holes were not noticed on the treated fabric. However, it was found that larvae exposed to treated fabric perished after four days while those exposed to untreated fabric lived for ten days before dying.

5. Conclusion

From the complete study it was concluded that essential oil chitosan nanoparticles were successfully developed. The average size of the developed nanoparticles was observed between 200-300 nm. The entrapment efficiency in neem chitosan nanoparticle was observed highest at 78% followed by cinnamon and clove chitosan nanoparticle. The antibacterial efficiency was observed highest by clove and cinnamon followed by neem. Despite of carom oil showing good entrapment efficiency, the MIC results did not support its efficacy towards microbes hence the oil was excluded. Camphor oil were discarded as camphor showed least entrapment being highly volatile and unstable. The efficiency of the nanoparticle coated fabric was tested by its EDX analysis and was also supported by their antibacterial, antifungal, and insect repellency test. The results proved that the finish can be coated on cotton fabric to use it as a covering material for the heritage textiles kept in storage to protect from microbes and insects. The fabric can also be used as a backing or a lining material when stored flat in shelves or drawers or as a padding on hangers and rollers, thus avoiding direct application to the ancient textiles. The finish being cost effective and stable with around 80% of the content until two months can be also used by individuals at home to preserve their textiles.

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