

Development of Odorless Fabric by Using Modified Complex Coacervation Technique

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ABSTRACT

To overcome odor problem, sweat degradation by bacteria is inhibited. In this research, modified complex coacervation technique involves formation of Nano capsules, which stores antimicrobial and fragrant compounds. Modified Complex Coacervation technique requires high-speed mixing of the solution to produce Nano capsules. In this research Sodium Alginate, Gelatin and Gum Arabic were used as wall materials. Aloe vera and peppermint essential oil were used in a core at equal weight with wall materials. Prepared coated samples by synthesized Nano capsules were characterized by Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), Formaldehyde Release Test and AATCC 100 test for antimicrobial activity for validation of formation of Nano capsules, which possessed antimicrobial and fragrant properties.

Keywords: Odorless fabric; fragrance fabric; sodium alginate; gum Arabic; gelatin; SEM; FTIR

INTRODUCTION

The odor is formed due to the degradation of wet sweat, which is deposited on the textile substrate, by bacterial activity. Textile articles can develop unpleasant odors that arise from many different sources, both internal and external to the human body. Textile odor can lead to consumer dissatisfaction, particularly as there are high expectations that clothing and textile products meet multiple aesthetic and functional needs (McQueen and Vaezafshar 2020, McQueen and Vaezafshar 2020, Van Herreweghen, Amberg et al. 2020). Understanding the formation of sweat malodor in textiles requires an exploration of the sweat composition, the microbial communities residing on our skin, and the chemical reactions that occur when these elements come into contact with textile fibers (Møllebjerg, Palmén et al. 2021). It was established that the absorption techniques were quite efficient to remove these odors; activated carbon and zeolite can be made into non-woven odor-absorbing sheets between two layers (McQueen and Vaezafshar 2020, Møllebjerg, Palmén et al. 2021). Malodor in textile material was caused by the degradation of the wet sweat, absorbed

by the textile substrate. Human sweat consists mainly of water, electrolytes, and trace amounts of metabolic waste products. However, it is the presence of certain compounds, such as amino acids and fatty acids that play a crucial role in the formation of sweat malodor (Robinson and Robinson 1954). The apocrine sweat was degraded due to the bacterial activity of the surrounding, which results in the formation of malodor compounds including free steroids, acids, and aldehydes (Obendorf, Kim et al. 2007). These bacterial activities flourish in warm and moist environments, making our sweat-soaked clothes an attractive breeding ground. As the microorganisms metabolize the organic compounds present in our sweat, they produce volatile organic compounds (VOCs) that are responsible for the characteristic unpleasant odor associated with sweat malodor (Chang and Wang 2023). Traditionally, the control of sweat malodor has involved the use of metals like silver or dendritic materials (Saleem and Zaidi 2020), as well as synthetic substances like Triclosan or Quaternary Ammonium Compounds (QACs) (Li, Gao et al. 2022). While these substances have demonstrated effectiveness in curbing bacterial activity and sweat decomposition, they present certain challenges. One of which is environmental sustainability concern, as some of these substances have

been found to have adverse effects on ecosystems. Additionally, the production costs associated with these substances may make them economically impractical for commercial use. Moreover, the overuse of synthetic antibacterial agents has also contributed to the emergence of bacterial resistance, reducing their efficacy against sweat malodor (Periolatto, Ferrero et al. 2017). Given the limitations of traditional approaches, researchers have now shifted their focus towards natural and sustainable alternatives to combat sweat malodor. Natural products such as Beta Cyclodextrin (Ibrahim, El-Zairy et al. 2017), Chitosan (Liu, Luo et al. 2022) (Ye, Leung et al. 2005) (Valle, Valle et al. 2021) (A, S et al. 2013), Sodium Alginate (Li, He et al. 2017), Gelatin (Ibrahim, Aly et al. 2019) and Gum Arabic (Tawiah, Badoe et al. 2016) have emerged as promising solutions. These environmentally friendly substances offer sustainable means to address sweat malodor. Furthermore, innovative techniques like Nano encapsulation provide a way to achieve controlled release of fragrant and antimicrobial agents, ensuring prolonged effectiveness (McQueen and Vaezafshar 2020, Møllebjerg, Palmén et al. 2021). In this method, researchers use a certain Nano or microcapsule as a wall material to trap fragrant molecules inside it and then would degrade over time to produce controlled fragrance release, along with preventing odor formation due to its antibacterial properties (Gülümser 2017). There are various application methods as well that involve printing, padding, immersion, coating, UV and microwave irradiations. In most researches the microcapsules were fixed onto the fabric through thermal processing carried out at high temperatures, this eventually leads to decrease life span of the microcapsules as well as breakage of the wall and escape of core materials. In other cases the encapsulated material was fixed using a binder, while most of them are synthetic chemicals that affect the internal fabric properties as well as could be toxic to human skin (Dedhia 2021). In some other researches, a micro emulsion method was also used for the formation of microcapsules, which could then be applied by padding method or by immersion of sample in the prepared emulsion bath (Ghayempour and Montazer 2016).

Gum Arabic, along with Gelatin was used to create nanoparticles by complex coacervation method (Rungwasantisuk and Raibhu 2020) worked on creating gift-wrapping paper with fragrance release properties. They used Gelatin and Gum Arabic to create microcapsules by complex coacervation. The microcapsules were then applied to the paper using screen printing. It was observed that the microcapsules gave a burst release by rubbing with fingers and at the same time maintaining the structural integrity required. The application of this recipe on textiles was not mentioned here. The research report claimed to investigate the efficacy of this wall material in imparting

a long-lasting and pleasant fragrance to the paper. Lavender essential oil, renowned for its soothing and aromatic properties, was commonly used in various personal care and cosmetic products. However, incorporating this oil into gift-wrapping paper presented a unique challenge as it also needed to retain its fragrance for an extended period. To overcome this, researchers explored the use of complex coacervation of Gelatin and Gum-Arabic (Sing 2017). In (Lv, Yang et al. 2014) determined the use of the Nano-encapsulation technique by Gelatin and Gum Arabic to create heat-resistant nanoparticles. The properties of the particles were tested to determine their efficiency. This article presented a comprehensive research report on the successful encapsulation of jasmine essential oil within nano capsules, which exhibit enhanced heat resistance and prolonged fragrance retention. This article mainly focused on food and flavor science, but it gave hints for modifying the technique for textile purposes. In (L. and S. S. J 2018) experimented with the application of lemongrass essential oil on a textile substrate by employing two methods: the exhaust method and the microencapsulation method. The fabric samples from both methods were compared and analyzed to determine the best method for controlled fragrance release. The result showed that microencapsulation by Gelatin and Gum Arabic wall material showed more durability for up to 30 wash cycles than the exhaust technique. The comparative analysis of lemongrass oil application on textile substrate through microencapsulation and exhaust method garnered significant attention in recent research. The results of the study demonstrated that both microencapsulation and exhaust methods were effective in imparting lemongrass oil fragrance to the textile substrates. Microencapsulation exhibited higher encapsulation efficiency, ensuring a more controlled release of the fragrance over an extended period. On the other hand, the exhaust method provided a more immediate and intense fragrance release, but with a relatively shorter duration. In (Specos, M et al. 2010) compared the microencapsulation of lemon essential oil by Yeast and by Gum Arabic/ Gelatin coacervation to analyze their results. The solution was evaluated in slurry liquid form as well as after application on fabric. The results obtained were satisfactory. However, encapsulation percentages found for Yeast microcapsules were between 21% and 27%, lower than expected for lemon essential oil. This research claimed to optimize the aroma finishing process by investigating different factors, including the type of fragrance, the concentration of microcapsules, and the application method. These factors were systematically varied to achieve desirable fragrance release and longevity on the cotton fabric. The research findings contributed to the development of innovative approaches to enhance the sensory appeal of cotton textiles through controlled fragrance release (Bezerra, Carmona et

al. 2016). The gelatin and gum Arabic recipe on cotton and polyester fabric, separately, to analyze the variation of fragrance release in different fibers. The results showed that Microencapsulation of the oil improved its thermal characteristics, making it less volatile and thus applicable to textile substrates in high-temperature processes. In (TT, TV et al. 2021) study explained the use of spray-drying technique to form microcapsules of essential oils with gum, modified starch, or maltodextrin as wall material. Essential oils, derived from plant sources, possess valuable properties such as fragrance, antimicrobial activity, and therapeutic effects. Microencapsulation of these oils offered a means to protect and deliver their active compounds in a controlled manner. Nano encapsulation of plant extracts in hydrogel Tragacanth gum through single-step in-situ synthesis. In this process, chamomile was extracted physically from the flower by sonication. The Tragacanth gum, a natural polysaccharide derived from the *Astragalus* genus, acted as a stabilizing and matrix-forming agent for the encapsulated plant extract. The durability and effectiveness of the nano-encapsulated plant extract on cotton fabric were evaluated through wash durability, colorfastness, and antimicrobial activity. The encapsulated plant extracts demonstrated excellent wash durability and colorfastness, indicating its ability to withstand repeated laundering without significant loss of efficacy. The weight of the fabric was also increased by 3.6 % compared with the raw cotton fabric (Ghayempour and Montazer 2016). An improvement of the antibacterial activity of moxa oil containing Gelatin and Gum Arabic Nano capsules were investigated. Moxa oil, derived from the *Artemisia vulgaris* plant, possesses antibacterial properties and was commonly used in traditional medicine for its therapeutic effects. The controlled release of moxa oil from the microcapsules contributed to its prolonged efficacy against bacterial strains. The research findings contributed to the development of innovative approaches for the controlled release of active compounds and the improvement of their therapeutic effectiveness but the article only showed the contribution of moxa oil towards a specific bacterium, *Staphylococcus aureus* (Li, Au et al. 2013). It was reported that the role of transglutaminase enzyme in hardening the Nano capsules formed by complex coacervation method. The evaluation showed that compared with formaldehyde, transglutaminase exhibits similar microcapsule hardening effectiveness but the release rate of essential oil from the transglutaminase-hardened microcapsules was slightly lower than that of the formaldehyde-hardened microcapsules. It exhibited successful optimization of cross-linking parameters, culminating in enhanced stability and strength of the transglutaminase-hardened multinuclear microcapsules. These fortified microcapsules demonstrated heightened resistance to mechanical stress and controlled, slow

dissolution rates (Dong, Xia et al. 2008).

In (A, S et al. 2013) reported that Chitosan nanoparticles are produced by the polymerization of chitosan. Chitosan in its nanoparticle state gives greater antimicrobial activity due to its greater surface area, hence they avoid degradation of sweat by bacteria. Chitosan nanoparticles can be applied to fabric using a cross-linking agent. It can be applied to the fabric by using modified dihydroxy ethylene urea as a cross-linker and can be used to enhance the functional properties of cotton by microencapsulation of various essential oils, as mentioned by (A, ZA et al. 2014) in their article. Microcapsules of chitosan can be applied to the fabric through different methods, including bath exhaustion, filling, pad dry cure, spraying, immersion, and grafting chemicals (Valle, Valle et al. 2021). Application of chitosan on jute fabric was also conducted but the results showed that bleached jute fabric showed no significant fragrance release due to the removal of added and adhered impurities during bleaching (NC, L et al. 2018). The results demonstrated that chitosan treatments effectively improved the antimicrobial properties of the fabrics but also compromising their elasticity and mechanical strength. The results showed a significant decrease in air permeability, bursting strength, and drapability, with an increase in stiffness of the fabric. The color fastness of the treated fabrics remained satisfactory, ensuring long-term aesthetic appeal. (Yıldız Varan 2018). It was reported that chitosan with Gum Arabic to produce Nano capsules with complex coacervation techniques. The result concluded that the antibacterial activity of fabric increases with the increase in chitosan concentration up to a limit, but it was also observed that some formulations were not suitable for grafting reaction and could not survive its high temperatures (Sharkawy, Fernandes et al. 2017). Another disadvantage of using chitosan in fragrance finishing was the increase in stiffness of the fabric, resulting in less drapability. To overcome this problem, researchers tried different approaches in their article (Karolia and Mendapara 2007) used silicone softener with chitosan to facilitate fragrance deposition which was almost a successful method. Another research provided valuable insights into the development of functional and desirable textile finishes that promote both cleanliness and sensory experience (Yıldız Varan 2018). Chitosan with silicone softener is also used for anti-inflammatory and anti-bacterial drug-delivering properties on cotton by using stabilized mesoporous silica particles but the results showed a decrease in tensile strength and stiffness due to the coating of the silica layer (Hashemikia, Hemmatinejad et al. 2016). In (Javid, Raza et al. 2014) conducted a research on role

of chitosan microencapsulation on various essential oils.

Beta cyclodextrin is a cyclic oligosaccharide. They are produced when glucosyltransferase (enzyme) and starch were treated together. They have hydrophobic cavities that can hold any organic compound like essential oils for fragrance and antimicrobial activity.(Ammayappan and Moses 2009). While the polar outside part of the cavity makes the Beta cyclodextrin cavities hydrophilic from the outside, this property of beta-cyclodextrin can be used for sweating entrapment, the release of perfume, and antimicrobial characteristics(Bezerra, Lis et al. 2020). During printing, dyeing and finishing stages to increase color strength in dyeing and printing as well as acting as host for small molecules of fragrant essential oils(El-Sayed, A Othman et al. 2021). Combined effect of fragrance and anti-microbial finish on cotton fabric with the help of lavender essential oil and beta-cyclodextrin was investigated. They also used grafted chitosan in the recipe to act as a cationic anti-microbial agent. Same method was used in (Singh, Ratnapandian et al. 2021) where lemongrass essential oil was used instead of lavender oil but the use of both, Chitosan and Beta Cyclodextrin would result in high cost of the end product which makes the recipe unsuitable for commercial use (Singh, Yadav et al. 2017). Cyclodextrin has hydrophobic cavities (inner walls), and they were capable of forming inclusion complexes with fragrant essential oils and ensuring their slower release which causes retention of fragrances for a longer period of time in cotton as well as polyester(Ghosh and Chipot 2015). For sustained fragrance-release textiles, beta-cyclodextrin was also incorporated in the poly Vinyl alcohol fibers in their amorphous region. The PVA fibers were produced by wet processing and cross-linked with glutaraldehyde (Xing, Xu et al. 2022) the experimentation didn't focus on implementing odor masking and antibacterial properties of the textile. Another article uses beta-cyclodextrin with an antimicrobial agent to provide anti-bacterial properties on a textile substrate, but the recipe requires a high amount of beta-cyclodextrin for greater effectiveness which imparts stiffness to the fabric(Abdel-Halim, Al-Deyab et al. 2014). Better fixation of beta-cyclodextrin onto cotton is a point of concern and requires a good cross-linking agent, Polyaminocarboxylic acid can be used for this purpose as suggested by(Dehabadi, Buschmann et al. 2014). A derivative of beta cyclodextrin, also known as MCT beta cyclodextrin, is also widely used in host guest applications and provides much better results(Khanna, Sharma et al. 2015). Similar to Chitosan, these molecules also contribute towards fabric stiffness which may become undesirable for end product. To overcome this problem, researchers also experimented with softeners, such as silicone and micro emulsion softeners (Jolaei 2016).

Sodium Alginate used for green textile finishing by using sol-gel method or by forming Nano capsules by complex coacervation mechanism(Li, He et al. 2017). It used as an adhesive binder in wool fibers or waste fiber composite material in technical applications(Lacoste, El Hage et al. 2018). in (Хармони and Зиад 2020) used it as shell material to encapsulate camphor powder for use in fragrance and anti-microbial finishing. The spherical shape of microcapsules indicated that Sodium Alginate can successfully become a novel shell material, but it was observed that the fragrance was lost about 15% after the first wash. Moreover, it was only effective for E. coli bacterium but did not show good efficiency against S. Aureus bacterium. Another research, conducting experiment on microwave curing of fragrant finished fabric, applied the finish on the fabric by using Sodium Alginate Nano capsules. The material not only showed good durability till 25 washes but also proved efficient against washing and rubbing tests(Ghayempour and Mortazavi 2015). The study shows that this material can be proved to be a potential shell material for green textile finishing.

In (McQueen, Keelan et al. 2013) Silver was used an antimicrobial agent and result showed that the effect of sweat components on silver-based components is clear and requires more attention. The most durable and most popular metal in the textile industry was silver. The renowned metal can be woven or impregnated within the textile fabric in order to kill bacteria that causes odor, although ecologists have shown a serious concern towards the excess use of such powerful antimicrobial agent, that it might negatively affect bacteria in natural environment if nano-anti microbials were released in waste streams. Dendritic material was a highly branched Nano polymer which can be used for odorless textile applications(Akbari 2013). Also, amine terminated dendritic polymers have potential applications host-guest chemistry, including dye, contaminant and finishing ability(Akbari and Kozłowski 2019) one disadvantage of these polymers was that they can change size, shape or sheet multiplicity of other Nano materials. Methyl methacrylate, along with styrene copolymer, can also be used for microencapsulation. The finish is durable after 15 washes, fragrance release rate of 6.8% after wash (Liu, Liang et al. 2015) but the potential danger of methyl methacrylate causing skin allergy limits its use for next to skin textile applications.

This research aim is to fill the gap of malodor by inhibiting sweat degradation and introducing pleasant fragrances in its place. Although, Beta Cyclodextrin and Chitosan proved to be an effective but expensive wall material for fragrance release, with a contribution towards fabric stiff handle as well. Although, fixation of chitosan was not a considerable issue but fixation of beta cyclodextrin onto fabric surface was a point of concern

and it required a cross linking agent. The proposed modified complex coacervation technique involves addressing mentioned problem by developing the Nano capsule mechanisms with two different wall materials called Gum Arabic and Gelatin, and Sodium alginate enclosing combo of peppermint and aloe vera essential oils. Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM), Formaldehyde release test and AATCC 100 test for antimicrobial activity validate the proposed low cost technique of developed samples.

METHODOLOGY

MATERIALS AND METHODS

Two distinct recipes were explored to create nano capsules, each with its Modified Complex Coacervation technique. The first recipe revolves the utilization of gum Arabic and Gelatin as the “wall material” to form nano capsules. The second recipe, Sodium alginate as the wall material for the nano capsules. These nano capsules serve as protective barriers, enclosing miser of by equal weight of aloe vera and peppermint essential oils through a process called complex coacervation technique. This intricate method involves the interaction of oppositely charged polymers, leading to the encapsulation of these valuable oils.

PRODUCTION OF GUM ARABIC AND GELATIN NANO-CAPSULES

In this recipe, two solutions of 1.5 grams of gelatin and gum Arabic were prepared by mixing with 40 ml of deionized water and heated till 50°C for dissolution.

Subsequently, 3 ml of aloe vera essential oil, 3 ml of peppermint essential oil, and 1.5 grams of span 80 (nonionic surfactant) were mixed in 20 ml of deionized water using a magnetic stirrer. The essential oil solution was stirred at 2000 RPM for 15 minutes, and then added to the prepared gum Arabic solution. The magnetic stirrer was set to 1200 RPM for 5 minutes to emulsify the solution before adding the gelatin solution and reducing the stirring speed to 400 RPM for 15 minutes, simultaneously lowering the solution’s pH to 4 with 10% acetic acid. The mixture in the beaker was placed in an ice bath to achieve a temperature of approximately 5°C to 10°C. A 25% formaldehyde solution was prepared and 6 ml of it was added to the essential oil, gum Arabic, and gelatin mix. The system was then stirred for 30 minutes while remaining in the ice bath. The pH of the solution was adjusted to 8-9 by adding 10% sodium hydroxide solution. The temperature was raised to 15°C, and the reaction system was continuously stirred for 2 hours to obtain aloe vera and peppermint nano capsules. After the stirring, a cloudy solution was obtained which was termed as “Nano emulsion” (See Figure 1a).

PRODUCTION OF SODIUM ALGINATE NANO-CAPSULES

The recipe mainly consisted of primarily three ingredients. Sodium alginate mixture of 1.5% (wall material) 3 ml peppermint oil and 3 ml aloe vera oil (core material) and 0.1% Tween 20 (used as an emulsifier) were mixed and stirred using a 24-kilohertz ultrasonic wave generating device that had a sonotrode. The stirring was done for 5 minutes, and then a 5% solution of calcium chloride was added into the micro-emulsion to obtain the nano capsules (See Figure 1b) by continuing the sonification process.

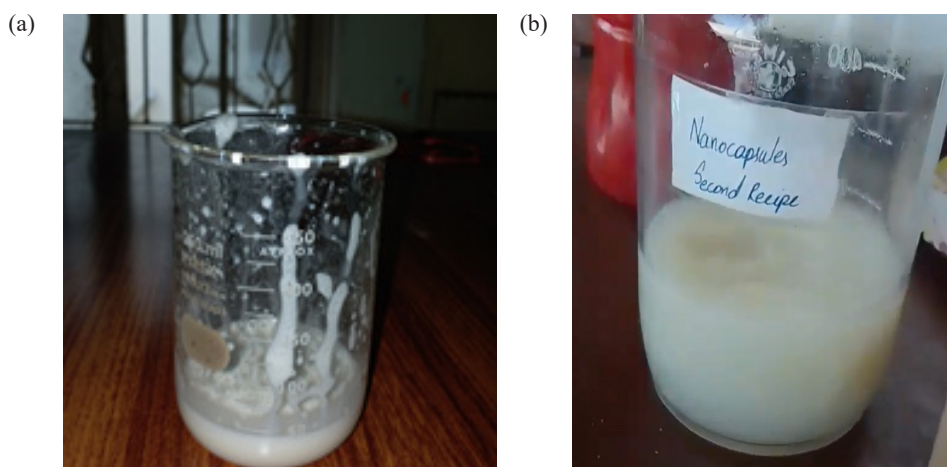


FIGURE 1. (a) Gum Arabic and Gelatin Nano-capsules;
(b) Sodium Alginate Nano-capsules

COATING TECHNIQUE

Immersion coating technique was used for sample preparation. Firstly, 100% cotton, plain weave, light weight (100 g/m²) was dipped into a solution of 10% acetone for 30 minutes, sample was rinsed with water, and it was dried at room temperature. Immersing the sample in the finishing bath (consist of 100 grams/liter of 3D resin, 2 gram/liter of catalyst MgCl₂, and 200 grams/liter of nano capsule emulsion) with the bath ratio of 1:30 for 30 minutes. Treated fabric was partially dried at 80 to 90-degree centigrade for 3 minutes and then baked at 110-120 degree centigrade for 15 minutes. This process was followed by cooling down at home temperature; the samples were finally rinsed and dried.

RESULTS AND DISCUSSION

FTIR ANALYSIS

Fourier Transform Infrared (FTIR) analysis provides a powerful technique for chemical composition and characterizing the composition of developed Nano capsules, enabling a comprehensive assessment of their functionality groups; encapsulated systems can release

active ingredients, such as fragrance, antimicrobial agents, or odor-neutralizing compounds, upon specific triggers.

GUM ARABIC AND GELATIN NANO CAPSULES

In the evaluation of Gum Arabic and Gelatin nano capsules using FTIR analysis, the obtained spectra (See Figure 2) revealed multiple characteristic peaks corresponding to their respective structural bonds. Notably, a prominent peak at 1710 cm⁻¹ indicated the presence of carboxyl groups (C=O), which aligns with the expected range of 1700-1725 cm⁻¹ (Espinosa-Andrews, Sandoval-Castilla et al. 2010). This peak is attributed to the stretching vibrations of carboxyl groups within the gum Arabic, further confirming its presence in the sample.

Additionally, another discernible peak at 2899 cm⁻¹ was observed, indicating the presence of aliphatic C-H bonds within the range of 2800-3000 cm⁻¹. This peak provides additional confirmation of the presence of gum Arabic within the analyzed microcapsules.

Regarding gelatin, the FTIR analysis revealed distinct features associated with its chemical structure. A broad peak at 3285 cm⁻¹, falling within the expected range of 3200-3500 cm⁻¹, indicated the presence of N-H stretching vibrations, specifically associated with the amide A region (Rousi, Malhiac et al. 2019). This peak provides evidence of the presence of gelatin, as the N-H bonds are characteristic of its amide groups.

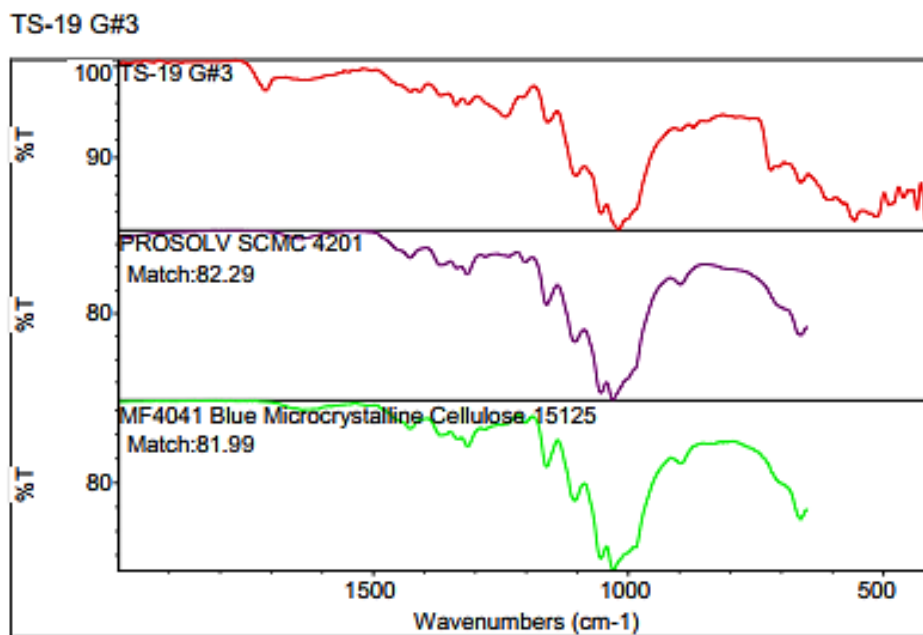


FIGURE 2. FTIR Spectra of Gum Arabic and Gelatin Nano-capsules

Furthermore, a strong peak at 1710 cm^{-1} , which closely aligns with the typical range of $1650\text{--}1690\text{ cm}^{-1}$, was observed, indicating the stretching vibrations of $\text{C}=\text{O}$ bonds within the amide I region. This peak serves as further confirmation of the presence of gelatin, highlighting the characteristic bonds within its amide groups.

SODIUM ALGINATE NANO CAPSULES

FTIR spectra analysis revealed significant peaks corresponding to the structural bonds' characteristic of Sodium alginate, (See Figure 3). Notably, a broad peak at 3330 cm^{-1} within the range of $3200\text{--}3600\text{ cm}^{-1}$ (Mahmud, Pervez et al. 2020) was observed, attributable to the stretching vibrations of the hydroxyl groups (O-H) present in Sodium alginate. This peak signifies the presence

of hydroxyl groups and contributes to the identification of Sodium alginate in the sample. Furthermore, another peak at 1017 cm^{-1} was observed within the range of $1000\text{--}1200\text{ cm}^{-1}$, indicating the stretching vibrations of the C-O-C bonds specific to Sodium alginate (Mahmud, Pervez et al. 2020). This peak provides additional evidence for the presence of Sodium alginate microcapsules, as the C-O-C bonds are characteristic of this compound. Additionally, a peak at 1710 cm^{-1} , closely aligned with the range of $1600\text{--}1650\text{ cm}^{-1}$ (Hecht and Srebnik 2016), was discernible due to the stretching vibrations of the carboxylate groups (COO^-) within Sodium alginate. This peak further supports the identification of Sodium alginate, as the presence of carboxylate groups is a distinctive feature of the compound.

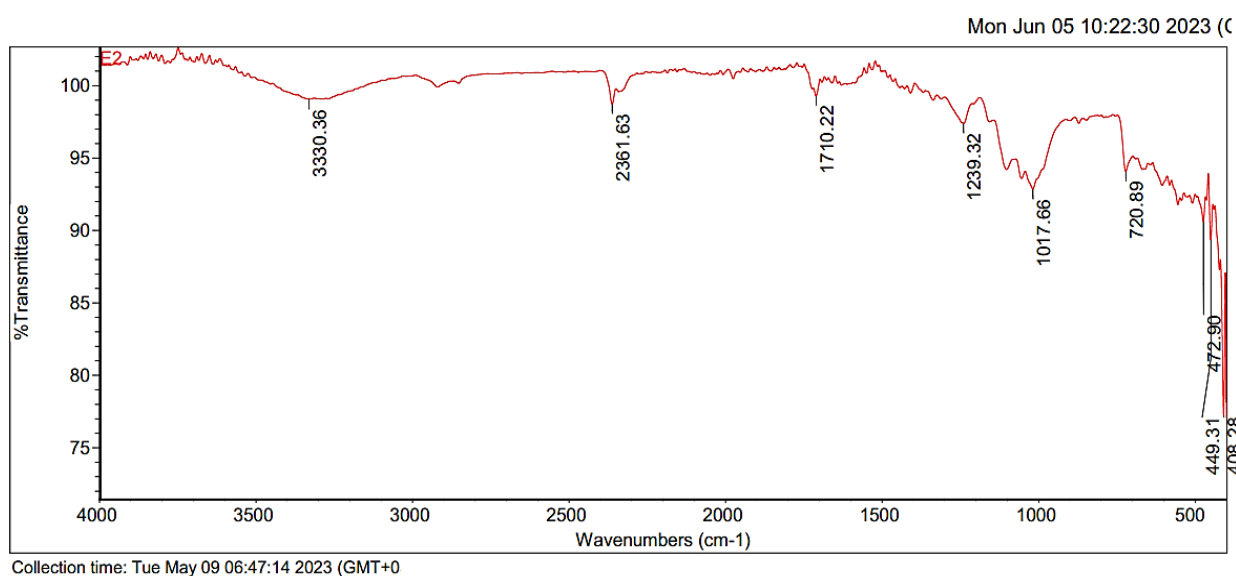


FIGURE 3. FTIR Spectra of Sodium Alginate Nano-capsules

SCANNING ELECTRON MICROSCOPY (SEM)

SEM works by scanning the surface of the sample with a focused beam of electrons. The sample is prepared by coating it with a thin layer of conductive material, such as gold or carbon, to enhance electron conductivity. The electron beam interacts with the sample, causing various signals to be generated.

GUM ARABIC AND GELATIN NANOCAPSULES

The gum Arabic and gelatin nano capsules, which encapsulate aloe vera and peppermint essential oil, can be

visualized using SEM (See Figure 2) to assess their structural integrity and surface features.

Magnification of Figure 4(a, b) at X2700 and X5000 was evident the distribution and arrangement of the encapsulated aloe vera and peppermint essential oil within the nano capsules. By examining the cross-sections of the nano capsules, SEM analysis enables visualization of the core materials and their encapsulation efficiency.

In Figure 4c, the energy-dispersive X-ray spectroscopy (EDS) showed the presence of Carbon and Oxygen molecules, which confirms the presence of Gum Arabic ($\text{C}_{15}\text{H}_{20}\text{NNaO}_4$) (Palumbo, Gorny et al. 2019, Chawla, Kumar et al. 2020) and Gelatin ($\text{C}_6\text{H}_{12}\text{O}_6$) (Yan, Dang et al. 2023).

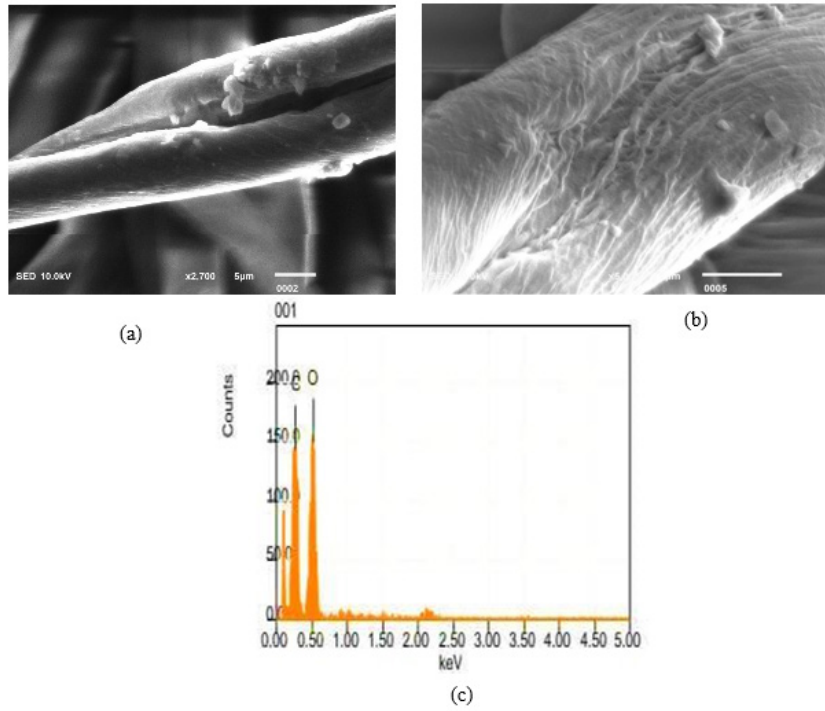


FIGURE 4. a), b) SEM; c) EDS

SODIUM ALGINATE NANOCAPSULES

SEM analysis of Sodium Alginate nanocapsules provides valuable information about their morphology, surface features, and encapsulation characteristics (See Figure3). This information is crucial for assessing the quality,

stability, and performance of the microcapsules used in the development of odorless clothing. Magnification of Figure 5 (a,b) at X1000 and X2500 was evident the distribution and arrangement of the encapsulated aloe vera and peppermint essential oil within the nano capsules, contributing to the optimization of their antibacterial properties and sweat reduction capabilities.

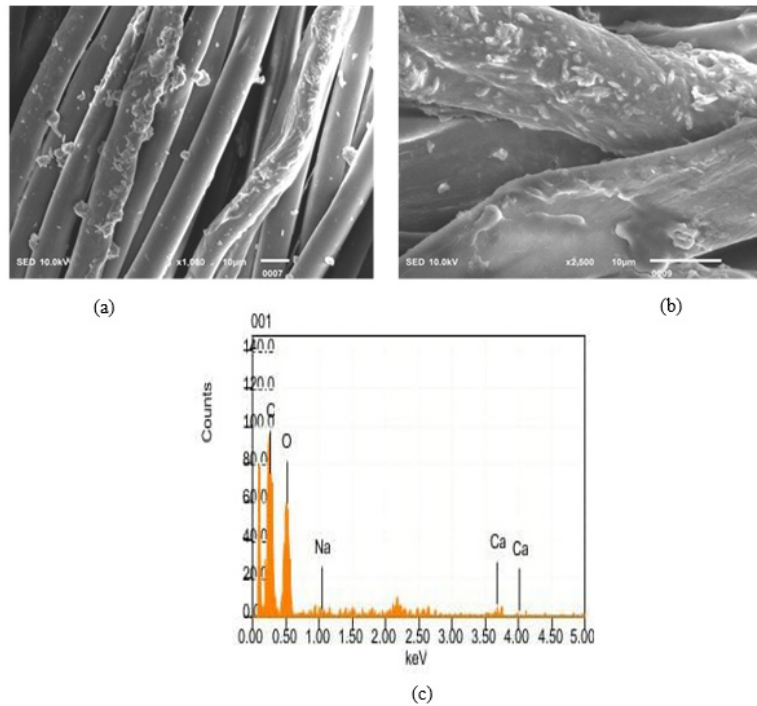


FIGURE 5. a), b) SEM; c) EDS

In Figure 5c, the energy-dispersive X-ray spectroscopy (EDS) showed the presence of Carbon, Calcium, Sodium, and Oxygen molecules, which confirms the presence of Sodium Alginate (Chen, He et al. 2023) ($\text{NaC}_6\text{H}_7\text{O}_6$) and Calcium Chloride (CaCl_2).

AATCC 100 TEST METHOD: EVALUATING ANTI-BACTERIAL EFFICIENCY

It assesses the ability of a finish to inhibit the growth of bacteria on a textile substrate. The test involves inoculating the textile sample with a standardized bacterial strain and measuring the reduction in bacterial colony-forming units (CFUs) after a specified incubation period.

ANTIBACTERIAL ACTIVITY IN SOLUTION BY DISC DIFFUSION METHOD

The antibacterial activity of the solution was also evaluated. The antibacterial activity of both the finish solutions (sodium alginate, gum Arabic and gelatin) was evaluated using the standardized Disc diffusion method. This qualitative analysis showed exceptional antibacterial efficiency of both sodium alginate finish and gum Arabic + gelatin finish against *K. pneumoniae* bacteria in Figure 9(A) and 9(B) and against *S. Aureus* bacteria in Figure 9C and 9D. The areas where the finish solution was placed in the agar plate got cleared due to the antibacterial action of both the finish solutions. This confirms that the finish solution possess antibacterial functionality that is needed for the anti-odor and anti-sweat characteristics of the textile.

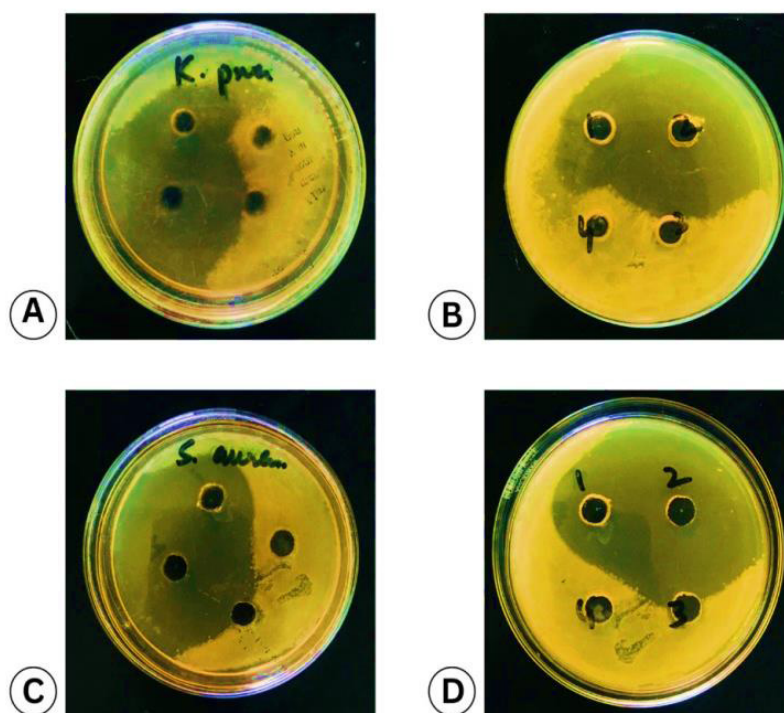


FIGURE 6. Antimicrobial Activity against *K. pneumoniae* of Gum Arabic and Gelatin (A); and Sodium Alginate (B); *S. Aureus* on Gum Arabic and Gelatin (C); and Sodium Alginate (D).

FORMALDEHYDE RELEASE TEST ISO 14184-1:2011

The ISO 14184-1:2011 test method provides release of formaldehyde magnitude from textiles has gained significant attention due to its potential health hazards.

Gum Arabic and Gelatin nano capsules, developed for anti-odor purposes, utilized formaldehyde during synthesis for cross-linking purpose. As per vapor absorption method, treated samples release formaldehyde 281.4 mg/kg which was less than threshold limit 300ppm. This result evident that proposed Modified Complex Coacervation technique of Gum Arabic and Gelatin nano capsules is suitable for odorless fabric for textile application.

CONCLUSION

The development of odorless fragrant textile products using nanotechnology-based microencapsulation techniques offers a promising solution to tackle malodor formation in textiles due to sweating. By encapsulating essential oils within protective nano capsules, the textile fabric can effectively control odor and emit a refreshing fragrance, thereby enhancing consumer satisfaction and comfort. FTIR, SEM and AATCC 100 test evident that the chosen wall materials; Arabic gum, gelatin, and sodium alginate, along with aloe vera and peppermint essential oil, demonstrate great potential with modified Complex Coacervation technique for achieving the desired outcomes. Further research for fragrance sustainability and optimization is under process. This direction could lead to the commercialization of innovative and sustainable textile solutions, benefiting both consumers and the textile industry.

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DECLARATION OF COMPETING INTEREST

None.

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